TRANSPORT AND ROAD RESEARCH LABORATORY

Department of Transport

CONTRACTOR REPORT 87

EVALUATION OF BUS LANES

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The authors of this report are employed by the Department of Civil Engineering, University of Southampton.

The work reported herein was carried out under a contract placed on them by the Transport and Road Research Laboratory.

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1988

ISSN 0266-7045

LIST OF CONTENTS

PAGE

SUMMARY

Buses with their high passenger capacity, are one of the most efficient forms of urban transport and a number of traffic engineering measures have been devised to give them priority over general traffic. Of the measures available, with-flow and contra-flow bus lanes have become widely adopted in the UK.

Guidance on bus lane design, selection and associated factors are contained in the DTp Technical Memorandum H6/76 and in TRRL reports LR809 and 918. However, since their publication, there have been significant changes in traffic composition, methods of traffic control and advances in techniques available for appraising traffic engineering measures. A review of bus priority measures has therefore been initiated, and this study,undertaken under contract to TRRL, relates to the evaluation of bus lanes.

The study has concentrated on deriving methods for predicting the principal effect of bus lanes, which is on the journey times of priority and non-priority vehicles, although all impacts are considered. This was undertaken by initially collecting data at 22 with-flow and 3 contra-flow bus lanes throughout the UK, covering parameters such as traffic flows and journey times for priority and non-priority vehicles. Such measurements allowed estimates to be made of the maximum journey time (and associated cost) savings for priority vehicles due to the bus lane. However, the prediction of the effects of the bus lanes on non-priority traffic required an assessment to be made of the suitability of three computer-based traffic models, TRAFFICQ, CONTRAM and BLAMP, and their application to all or a sample of the study sites. This application involved initial 'calibration' of the models to reflect existing traffic conditions at each site followed by further modelling with the bus lane(s) removed to obtain predictions of 'without' bus lane journey times. These results have enabled predicted economic benefits/ disbenefits of each bus lane to be determined.

A step-by-step procedure for evaluating bus lanes, using either modelling or non-modelling techniques as appropriate, has also been developed and is described in the report. This procedure is illustrated using data from two bus lanes recently introduced in London, where we have carried out 'before-and-after' surveys which have also allowed elements of the evaluation procedure to be validated.

SECTION ONE

INTRODUCTION

1.1 BACKGROUND

It can be argued that buses provide one of the most efficient forms of transport in urban areas, offering a much higher passenger capacity compared to the private car while only taking up about twice the road space. However, the flexibility and convenience of the private car has led to car ownership increasing consistently over the past 30-40 years largely at the expense of bus patronage. For example, vehicle mileage by car and taxi between 1974 and 1984 increased by 35%[1] (from 164 to 221 billion vehicle kilometres) while the equivalent increase for buses and coaches was only 8%. Over the same period passenger journeys by bus and coach fell by 25% (from 8312 to 6237 million).

One effect of increasing car usage has been the growth in traffic congestion in urban areas, which has also had a detrimental effect on the efficient operation of bus services, possibly leading to further reduced patronage. Considerable success has been achieved in recent years in combatting congestion by a range of traffic management measures, such as the restriction of on-street parking, improvements in junction design and the introduction of Urban Traffic Control (UTC) systems such as TRANSYT and SCOOT[3]. Nevertheless, congestion is still a feature of many urban streets in peak periods, and ways of protecting buses from this congestion have been sought. Thus, 'Bus Demonstration Projects' were introduced in the early 1970s under sponsorship from the Ministry of Transport (e.g. the Bitterne Bus Priority scheme in Southampton[4]) and their success was followed by the introduction of a large number and range of bus priority measures around the country. These measures have included:

- With-flow bus lanes (those reserved for buses travelling in the same direction as the general traffic)
- Contra-flow bus lanes (those reserved for buses travelling against the general traffic)
- Bus-only streets
- Priority at junctions (e.g. exemption from turning prohibitions, automatic detection of buses at signals, etc.)

One of the most common bus priority measures adopted has been the bus lane, with some 400 now in operation throughout the country. London, with its severe congestion problem, contains around half of these bus lanes, even though only some 18% of total bus passenger journeys in the UK are carried by London Regional Transport[1]. With-flow bus lanes have been installed more frequently than contra-flow lanes, the ratio between these types of bus lanes being of the order of 5:1.

The rate of implementation of new bus lane schemes has diminished markedly since the mid-1970s and, in some areas, schemes have been abandoned. The reasons for this decline are uncertain, although there may well be both political and technical elements involved. On the technical side, it is likely that the 'best' schemes (i.e. those producing most benefits) were introduced first and subsequent schemes have been more marginal. There have also undoubtedly been some bus lanes introduced that have produced a net disbenefit and the uncertainties associated with the effects of a bus lane may well have prevented a number of schemes progressing. Bus lanes have not generally been considered to have reduced the continuing decline in bus patronage, and many local authorities have looked towards schemes as part of a comprehensive traffic management strategy.

A further problem in the appraisal of bus lane schemes has been that of evaluation. While it appears that most local authorities carry out some evaluation prior to implementation of a scheme, there are no standard procedures recommended by the Department of Transport, although Technical Memorandum H6/76[5] remains in force for design guidance. Theoretical studies at T.R.R.L., described in LR809[6] and LR918[7], produced relationships for assisting with the selection and design of with-flow and contra-flow bus lanes and gave suggested evaluation procedures. However, these reports do not appear to have been widely adopted by practising engineers.

Many local authorities now take advantage of recently developed computer models to appraise a variety of traffic management schemes, which may well include the evaluation of either new or existing bus lanes. There is clearly a need, therefore, for guidance on procedures which should be adopted for such an evaluation (e.g. model choice, methods of modelling, uncertainties and circumstances where modelling may be inappropriate, etc.). This study has concentrated on the development of these evaluation procedures for both with-flow and contra-flow bus lanes, by the application of computer models and simpler analytical techniques, to data collected at some 25 bus lane schemes throughout the UK.

1.2 STUDY OBJECTIVES

The three main study objectives, as defined in the study specification were:

(i) to provide a comprehensive description of the potential impacts and effectiveness of each type of bus lane under a wide variety of local circumstances

(ii) to devise and demonstrate a consistent methodology for the planning, appraisal and, where appropriate, the implementation and monitoring of bus lanes

(iii) to provide technical, operational and other relevant information on the salient features of each bus lane type under a variety of conditions as the basis of future guidance to local authorities.

Within these objectives, the study was also intended to extend the results of previous work, particularly H6/76[5], the T.R.R.L. studies, LR809[6] and LR918[7] and the recently completed initial assessment of the evaluation of bus lanes by the Consultants, Jamieson Mackay and Partners[8].

The study was to also take account of similar work being undertaken in London by the Consultants, Colin Buchanan and Partners for London Regional Transport. With this work in progress, sites in London were to be excluded from our study.

The study was to involve the collection of relevant data at a range of bus lane systems throughout the U.K. (25 such systems were eventually covered) and the derivation of an assessment methodology based both on the application of suitable computer models and on simpler techniques where possible. The computer models considered were TRAFFICQ[9] and CONTRAM[10], both of which were supported by the Department of Transport, and the new model BLAMP[11], developed by West Yorkshire Metropolitan County Council specifically for studying the operation of with-flow bus lanes. Recommendations were also required concerning the circumstances in which different appraisal techniques may be applied.

The results of the study were to be presented in a form suitable for promulgation to Local Authorities, subject to Department of Transport approval. These should cover the rationale, assessment, design and monitoring of each type of existing or proposed bus lane.

The study specification required that the work be completed by the end of February 1986, giving a contract period of some seven months. This was subsequently extended to allow examples of the evaluation procedure to be compiled using data collected at two sites in London where bus lanes have recently been introduced. Delay in implementing the bus lane meant that a further extension was necessary to enable an 'after' study to be undertaken to give an independent assessment of the evaluation procedure.

SECTION TWO

METHODS OF APPROACH

2.1 EXISTING EVALUATION METHODS

The Department of Transport's Technical Memorandum H6/76[5] 'The Implementation of Bus Priorities' was issued in 1976 and is still in force. It includes a description of each type of bus priority system commonly in use, and gives guidance on the planning and design of such systems. While some information is given concerning the likely effects of each type of system (e.g. on bus reliability/journey time) guidelines for evaluating bus priorities are not included, nor are warrants for their implementation. Work in this area was conducted by T.R.R.L. both for with-flow and contra-flow bus lanes, using a theoretical model.

The work undertaken at T.R.R.L. into the economic justification of with-flow bus lanes[6] looked at the factors controlling the benefits of bus lanes and then produced warrants for their implementation, based on changes in travellers' time and vehicle operating costs. Benefits were calculated for a range of traffic flows, compositions, signal settings and road layouts. Warrants were produced in terms of the minimum flows of priority vehicles required for their benefits to equal the disbenefits to non-priority traffic for variations in:

- the degree of saturation of the junction
- the proportion of green time available to the approach
- setback (either an optimum setback or no setback)
- ease of diversion for non-priority traffic
- permitted users (e.g. buses only; buses and taxis; buses, taxis and HGVs)

A manual was also included to enable transport planners to decide whether the installation of a reserved lane at a particular site was likely to be beneficial and to give advice on the main aspects of design.

Following their work on with-flow bus lanes, a theoretical model was again used to assess benefits and warrants for contra-flow bus lanes, as described in LR918[7]. General warrants in terms of minimum bus flows required to economically justify the bus lane were calculated for variations in:

- the total flow of non-priority vehicles
- savings in bus journey time
- savings in passenger walking time

The variation in network layout and forms of junction control between contra-flow lanes led to a detailed examination of four hypothetical situations. This study highlighted the sensitivity of the warrants to junction control characteristics and it was suggested that, for most situations, it would be necessary to carry out a specific economic assessment. A standardised assessment methodology was then formulated for calculating the appropriate warrants and the economic benefits for any given scheme.

A considerable amount of information on bus priority systems around the world is contained in the NATO report of 1976[12]. This report describes both with-flow and contra-flow bus lanes in detail, including such items as their advantages and disadvantages, design considerations and warrants for implementation. A methodology is also included for the assessment of bus priority measures, based on the comparison of detailed information collected before and after the implementation of a scheme. Some guidance is given concerning the circumstances under which net benefits or disbenefits are likely to occur. For with-flow lanes this is related to such factors as the degree of saturation and the provision or otherwise of a setback. For contra-flow lanes a main conclusion was that: "Because the traffic flow capacity lost on installation of a contra-flow lane is generally unimportant to the efficient working of a one-way traffic system, contra-flow lanes may be economically worthwhile at much lower bus flows than for with-flow lanes".

Guidance given in the publications described above on the likely benefits and warrants for bus lanes is likely to offer a good basis for deciding whether or not to continue with a more detailed evaluation of the bus lane. The warrants were necessarily based on a limited range of input parameters and it is unlikely that they would be sufficiently comprehensive to cover the situation at any one site (e.g. traffic diversions may not be able to be assessed in the way assumed in the original model, or traffic demand may exceed capacity for part of a peak, a condition not covered in the warrants). There is therefore a need for a general evaluation procedure which can cater for site-specific variations in key parameters and which can adequately predict the effects of installing or removing a bus lane. The methods of approach for formulating this evaluation procedure are described below, prior to more detailed analyses in subsequent sections.

2.2 METHODS OTHER THAN MODELLING

In ideal circumstances, a bus lane will not cause significant additional delay to non-priority vehicles and little benefit will then be gained from computer modelling. Such circumstances would be, for example, where there is no reduction in junction capacity and the increased queue length caused by the bus lane has no adverse effects (e.g. it does not block minor roads or upstream junctions or cause undesirable traffic diversions). In this situation the re-distribution of queues and delays between priority and non-priority vehicles can be assessed by simple calculation. The method of assessment and the circumstances in which it is appropriate are described in Section 8.

In other, more complex situations, or where different designs are being evaluated, computer modelling may be appropriate as described below.

2.3 COMPUTER MODELLING

A number of computer models have become available over the past decade for evaluating certain features of transport systems and/or aiding design. While all such models have an inherent degree of uncertainty, being based on relationships and procedures which are themselves uncertain, they can be particularly useful for assessing for example the effects of changes in key input parameters, as well as for performing calculations that would be extremely time consuming to perform manually. For example, the modelling of traffic movements in an urban network will involve several calculations of queue length and delay for each link, under conditions of time varying traffic demand. Thus, a number of models have been developed in recent years to look at traffic performance both on an individual link basis (e.g. ARCADY[13], PICADY[14] and OSCADY[15]) and on a network basis (e.g. TRAFFICQ and CONTRAM[10]). These models, particularly those described above which have Department of Transport recognition, are now widely used by many Local Authorities. It would clearly be of benefit if such models could be used for the evaluation of bus lanes, and this possibility has been investigated in detail in this study.

The recent study by Jamieson, Mackay and Partners (JMP[8]) concluded that TRAFFICQ could adequately reflect existing and before situations (i.e. with the bus lane removed) thus allowing the benefits of a scheme to be evaluated. This conclusion was based on the results of the model application to 12 with-flow bus lanes where congestion was not acute. Further assessment of this model was therefore proposed for this study. The assessment has included a series of sensitivity tests to determine those factors which significantly affect the key ouputs (e.g. queue length, delay, etc.), a critical comparison of the various methods of modelling bus lane systems, and the application of the model to each site surveyed.

The CONTRAM model developed at T.R.R.L. was also considered as being possibly suitable for the evaluation of bus lanes, although no previous assessment had been undertaken. It was therefore proposed initially to apply CONTRAM to a limited sample of with-flow and contra-flow bus lanes and assess the program in a similar manner to that described for TRAFFICQ above. During the course of the study it became clear that such a limited assessment of the program would be insufficient and extra resources were made available to carry out a more rigorous appraisal of the program, including its application to each of the study sites.

The Bus Lane Algorithmic Modelling Program (BLAMP[11]) developed at West Yorkshire Metropolitan County Council became available to the study in its early stages, and evaluation of this model was clearly worthwhile. This model, developed for single links containing a with-flow bus lane was assessed on a sample of such sites.

Although other computer models were available which could have been potentially suitable for the application required, it was decided to test only the three models listed above, as they were either supported by the Department of Transport (TRAFFICQ and CONTRAM) or were written specifically for the modelling of bus lanes (BLAMP). It is considered, however, that the suite of programs ARCADY, PICADY and OSCADY, developed at T.R.R.L. for the assessment of capacity and delay at roundabouts, priority intersections and traffic signals respectively could be used to study the effects of a with flow bus lane on individual links. This possibility could not be assessed within the scope of the study, however, although further comments in this respect are contained in Section 10.

2.4 OTHER CONSIDERATIONS

The evaluation methods/proposals briefly described above have concentrated on what is usually the key aspect in the cost effectiveness of a bus lane - savings in overall journey times and associated costs. However, a number of other factors may also be of importance at any one site and these are considered in the following sections.

SECTION THREE

CHARACTERISTICS AND POTENTIAL IMPACTS OF BUS LANES

3.1 WITH-FLOW BUS LANES

With-flow bus lanes, which are one of the most common forms of bus priority, may be defined as "traffic lanes reserved for bus use where buses continue to operate in the same direction as the normal traffic flow". In many areas use of this reserved lane has been extended to include other road users such as pedal cycles, taxis and coaches. Nearly all with-flow bus lanes are adjacent to the nearside kerb, although in a few cases the lane adjacent to the centre line of the road has been utilised. In the case of one-way streets, some with-flow lanes have been installed adjacent to the offside kerb. Most with-flow bus lanes are located on central area main roads or on main radial routes to town centres, where bus flows are relatively high and congestion causes significant delay.

Potential Benefits

With-flow bus lanes allow buses, and other permitted users, to by-pass other queueing vehicles, acting essentially as queue-jumping devices, and they provide free running conditions for buses along their length, provided violations of the bus lane by non-priority vehicles are not significant. While the queue-jumping mechanism is usually the cause of improved speeds for buses, significant benefits can also be gained through reductions in the levels of parking. Benefits may accrue to bus passengers in terms of reduced travel time, reduced waiting time at bus stops and an improved service quality (e.g. improved reliability). In some cases, bus stops may be able to be re-sited to reduce walking time. For the bus operator, there are likely to be reductions in service costs and a possible increase in revenue if more passengers are attracted to the service following the priority. Permitted users other than buses may also benefit from savings in travel time, vehicle operating costs and associated factors. Pedal cyclists may not benefit in this respect, although the reduction in accident risk through their being segregated from general traffic may be significant. Benefits of a bus lane to non-priority traffic are likely to be small, being mainly related to the advantages of traffic segregation by vehicle type in some circumstances (e.g. the possibility of a non-priority vehicle being 'trapped' behind a bus at a bus stop is avoided).

Possible Disbenefits

The main potential disbenefits of a with-flow bus lane which need to be assessed are:

(i) They may cause an increase in traffic congestion and consequent disbenefits to non-priority vehicles
(ii) Parking restrictions during the operational period of the bus lane may restrict access to kerbside properties
(iii) A high level of enforcement may be necessary to prevent non-priority vehicles using the lane
(iv) Accident risk may be increased

The minimum effect of a bus lane on non-priority traffic is that a potential queueing lane is lost (assuming that parking was not prevalent before its introduction). This in itself may not effect journey times for non-priority vehicles (other than as caused by overtaking buses) provided the critical capacity in the system (usually the downstream junction) is not reduced. However, it is possible that an increase in queue length alone, which accompanies all with-flow bus lane schemes may cause:

- Blocking back across minor road entries upstream, thus adversely affecting traffic not wishing to use the bus lane link
- Non-priority vehicles to divert away from the bus lane link to avoid the extra queue length caused by the bus lane. This may cause extra delay to these vehicles and to other vehicles on the adjacent links as well as being environmentally undesirable. Such diversions could occur locally or even over a wider area.

Where a bus lane causes a loss in downstream junction capacity, perhaps through the provision of too short a setback, non-priority vehicles may suffer considerable disbenefits, particularly where traffic demand is close to or in excess of capacity. Not only will these vehicles suffer extra delay, but the potential problems of blocking-back and traffic re-assignment are exacerbated.

There are a number of other factors which may have a detrimental impact on non-priority traffic following the introduction of a bus lane. These include:

- A reduction in speed due to the reduction in link capacity.

- The effect on following through traffic of right turning vehicles leaving the bus lane link; the presence of the bus lane may inhibit 'inside' overtaking.
- Effects associated with the bus lane layout, such as a reduction in lane width for vehicles travelling adjacent to the bus lane or in the opposite direction. (It should be noted that bus running speeds may also be reduced where lane width is restricted, either in the bus lane itself or in the immediately adjacent lane.) A further problem could be that of the location of the start of the bus lane. If this is too close to an upstream junction then the merging operation may be affected and the exit constriction may result in a loss of upstream junction capacity.

These factors are considered in more detail later in the report.

3.2 CONTRA-FLOW BUS LANES

Contra-flow bus lanes may be defined as 'traffic lanes reserved for buses travelling in the opposite direction to the normal traffic flow'. A typical location of a contra-flow lane is in a one-way traffic system, where buses are allowed to travel against the general traffic flow so avoiding a possible lengthy diversion. In many cases, the contra-flow lane merely restores to the bus service the more direct routeing it enjoyed before the introduction of the one-way system, although in the absence of other traffic, running times may be significantly shorter and more consistent. (The inconvenience to bus passengers of bus stops on an inbound and outbound route being separated by a one-way system can be considerable and result in a significant loss of patronage without a contra-flow lane.)

Contra-flow lanes are normally sited next to the nearside kerb and separated from opposing traffic by a continuous white line, although occasionally a physical separator such as a raised kerb may be adopted. Contra-flow lanes are normally restricted to buses only, although in some cases pedal cycles and taxis have been included.

Potential Benefits

While with-flow bus lanes are generally most beneficial in that they allow buses to overtake queues of non-priority traffic, the main benefit of contra-flow lanes is in the avoidance of lengthy diversions that usually accompany one-way systems. Thus, while both priority measures offer journey time and associated cost savings to bus travellers and operators, contra-flow lanes offer a distance as well as a time advantage. There are also benefits to general traffic through their being fewer buses and bus stops along the general traffic route. Many of the benefits listed above for with-flow lanes are also applicable to contra-flow lanes.

Possible Disbenefits

Many of the possible disbenefits of a contra-flow lane are similar to those of a with-flow lane with some exceptions: Being predominantly a 24 hour facility, enforcement problems are usually considerably reduced. Also, a contra-flow lane does not reduce the queueing space for other vehicles on the diversion route. However, a number of other possible disbenefits can occur with a contra-flow lane, such as:

- The junction layouts at one or both ends of the contra-flow lane are likely to require modification (e.g. incorporation of signal control, channelisation, etc.) to minimise conflicts. These modifications may both be expensive to install, and may even reduce capacity for non-priority traffic, so increasing delays.
- Accident hazard to pedestrians may be increased as they may be unaware of buses running against the normal one-way flow.
- The loss of capacity and queueing space for non-priority traffic on the bus lane link. In some circumstances this could cause problems of blocking-back and traffic re-assignment, as described above for with-flow lanes.

Being 24 hour facilities, loading and unloading can present a particular problem with contra-flow lanes: This either has to be transferred to adjacent streets/accesses, or limited stopping has to be permitted requiring buses to pull out against the general traffic flow to overtake.

Further evaluation of these factors is described in the following sections.

3.3 EFFECTS ON OTHER TRAFFIC

Apart from traffic using the bus lane during its period of operation, other traffic may also be affected by a bus lane. This includes traffic:-

- Emerging from side roads to join or cross the bus lane links.

- Travelling in the opposite direction to that on the bus lane link.
- On neighbouring links affected by vehicles diverting from the bus lane link.
- Using the link outside its period of operation.

The effect of a bus lane on side road and cross traffic is uncertain and likely to be highly site-specific. Delay may be increased because of the smaller number of suitable gaps in the non-priority traffic stream, as this traffic has been concentrated into fewer lanes. On the other hand, side road vehicles entering from the left may enter the bus lane before joining the non-priority stream and perhaps incur less delay. Where a queue of non-priority vehicles extends past the side road the situation is still uncertain - the side road may be effectively blocked - resulting in increased delay, or main road drivers, when stopped, may be more inclined to offer gaps to those on the side road. In either event, once on the main road, side road traffic will incur reduced delay with the bus lane - at the expense of following main road vehicles - as the number of queueing vehicles between the side road and the downstream junction has been reduced. These various effects are difficult to quantify without detailed 'before and after' information but are likely to be of minor overall significance where side road flows are low. These effects are further discussed in Section 8.

Traffic in the opposite direction to the bus lane may be at a disadvantage where the road centre line has had to be offset to accommodate the bus lane particularly if an effective lane width is lost. (This is nearly always the case with a contra-flow lane.) Such effects may require detailed assessment but were not considered significant at the study sites and have not been quantified.

Where a bus lane causes some traffic to be re-assigned to alternative routes, traffic on these routes, including buses, may suffer increased delay. The extent of this increased delay will depend on the existing traffic intensity and the volume of traffic re-assigning. Methods of assessing these effects are discussed in Section 8.

The effects of a bus lane outside its period of operation depend largely on the degree to which 'non-priority' traffic reverts to using the nearside lane (which may be largely influenced by relaxations in parking/loading restrictions) and to the volume of this traffic. It is likely that some of the benefits/disbenefits of the bus lane may continue outside its period of operation, but the extent of these effects is likely to be small, and could not be quantified within the scope of this study.

SECTION FOUR

MEASURES OF PERFORMANCE

It is clear from the previous sections that a key measure of performance of a bus lane is the change in overall time savings to vehicle occupants. The evaluation of a proposal for a bus lane, or its removal, therefore requires a knowledge/prediction of the separate effects of the bus lane on the journey times of priority and non-priority vehicles. If these effects can be measured or predicted accurately a range of associated impacts covering such factors as bus reliability, vehicle operating costs and environmental effects can be assessed.

Journey time can be considered to be made up of a 'cruise time' on the link, where speed/flow effects may be significant, and a delay associated with the downstream junction(s), which varies according to the traffic intensity of the junction (i.e. the ratio of the traffic demand to the junction capacity). Where the bus lane could affect the capacity of the junction, perhaps because of a short setback, junction delay becomes a critical parameter. A knowledge of queue length is also of importance as this frequently governs the optimum length of the bus lane and allows the possibilities of vehicle diversions, blocking back and associated effects to be examined. For buses, the 'cruise' speed along the bus lane is usually of major importance, as it is normally intended that buses by-pass most of the junction delays suffered by non-priority vehicles.

The criteria listed above i.e. vehicle speeds, journey time/delay and queue length, are considered in detail in the following sections, where factors influencing them are discussed. The methods and assumptions adopted concerning the analyses of these factors in subsequent sections are also given.

4.1 VEHICLE SPEEDS

Speeds in the Non-Priority Lane(s)

Vehicle speeds on urban/suburban links are related to a number of factors, such as the speed limit, speed/flow effects based on link geometry and other factors such as those contained within COBA[20], the degree of parking/loading, and the frequency and use of bus stops. On links where the degree of parking and/or bus stop usage is high, considerable disruption may occur when vehicles have to pull out of the nearside lane, both to these vehicles and to those following. Under these circumstances, a bus lane may result in an increase in vehicle speeds both for priority and non-priority vehicles, particularly where parking is largely eliminated. The quantification of the effects of parking on traffic speed are difficult, particularly where it is intermittent. Results based on measurements from this study are given in Section 8. It should be noted, however, that considerable benefits to all vehicle classes could be achieved by restricting on-street parking alone, without the introduction of a bus lane.

However, for links without bus stops or parking, traffic speeds will normally be governed by the speed limit or speed/flow effects. The introduction of a bus lane could have a detrimental effect on the speed of non-priority traffic through the restriction in the number of lanes available for their use and the consequent increase in traffic flow per lane. This effect can be exacerbated where non-priority traffic is restricted to a single lane and right turning vehicles delay following traffic. The quantification of this reduction in speed for non-priority traffic due to the loss of link capacity is difficult to ascertain without measurement. Its prediction using 'appropriate' speed/flow curves would be subject to considerable uncertainty but could give an 'order of magnitude' estimate.

In practice, most bus links have a range of properties, some of which would, on their own, cause an increase in vehicle speed and some a decrease. Experience in London[21], where the frequency and use of bus stops is relatively high, indicates that non-priority vehicle speeds are, on average, unaffected by the introduction of a bus lane, despite the loss in link capacity. However, many of these schemes were introduced with other traffic management measures, and the effect of the bus lane alone is difficult to quantify.

It should be noted that a reduction in link speed caused by a reduction in link capacity does not affect travel time if there is a queue of any length constantly present on the link. It merely results in an increase in 'link' delay and a decrease in 'queueing' delay, the total delay being unaffected. This is the situation that normally occurs at bus lanes during peak periods. For the reasons given above, no change in link speeds for non-priority vehicles have been assumed between the 'with' and 'without' bus lane situations in subsequent analyses. Any disbenefit to these vehicles under low flow conditions are likely to be small.

Speeds in the Bus Lane

An improvement in average speed for priority vehicles is expected to be a main benefit of a bus lane. This may be due not only to a reduction in the time spent queueing but also to improvements in cruise speed due to the segregation of priority and non-priority vehicles. The extent of this latter improvement is likely to be related to such factors as bus lane width, the extent of parking and moving violations, the proportion of cyclists in the bus lane and the frequency and use of bus stops. However, where a bus lane contains a high proportion of bus stops and high bus flows, bunching can occur as buses are not so easily able to overtake one another, particularly where a queue of non-priority traffic has formed adjacent to the bus lane. The quantification of this effect is particularly difficult and, as it is likely to be of minor significance, has not been attempted in the accompanying analyses. An assessment of bus cruise speeds for the sites surveyed is given in Section 8.

Merge Effects at the Taper

The commencement of a bus lane causes non-priority traffic to undergo a merging manoeuvre as the number of available lanes is reduced by one. The effect of this merge depends largely on the level of traffic flow particularly in the nearside lane and its location relative to the upstream junction. Where flows are high, traffic interactions and consequent reductions in speed will also be higher, although the provision of a taper usually prevents the formation of standing queues in the nearside lane. Speed reduction/delays caused by merging manoeuvres have been estimated elsewhere for other merging situations and relationships have been produced for their prediction; such effects are also incorporated within two of the traffic models examined in this report. The magnitude of such effects is discussed in Section 8.

The location of the merge point relative to the upstream junction is also significant. If it is located close to the exit of the junction, junction capacity may be reduced due to this exit constriction, and there may be insufficient 'room' for the merging manoeuvre. This has the effect of discouraging use of the nearside lane, thus, further restricting 'effective' capacity for non-priority vehicles. Again, these effects are incorporated within two of the traffic models examined in this report.

4.2 JUNCTION CAPACITY AND DELAY

In many cases, with-flow bus lanes have been installed to allow buses to avoid queues caused by a junction or other bottleneck which has restricted capacity at the end of the link.

An understanding of the factors controlling junction capacity and delay, which is itself dependent mainly on the ratio of traffic demand to junction capacity, is important if the effects of a bus lane are to be adequately assessed. These factors are considered below for the different junction types.

Traffic Signals

The capacity of an approach to a signal controlled junction depends on the amount of 'effective' green time available to the approach per cycle and the 'saturation' flow of vehicles discharging during this period. (The effective green time is the actual green plus amber time per cycle minus the lost times at the start and end of each phase due to acceleration/deceleration effects, and saturation flow is the maximum queue discharge rate.) Capacity can also vary between different streams on an arm which have different saturation flows and/or signal timings.

Delay increases non-linearly with increasing traffic intensity (demand/capacity) as shown in the example in Figure 8.1 although the form of signal control also has an effect. For example, signals can operate under vehicle actuation, fixed time control, or within a linked Urban Traffic Control system.

The effect of the introduction of a bus lane on a link whose downstream junction is signal controlled depends mainly on the reduction in capacity (if any) that may result. If signal timings remain unaltered, junction capacity is directly related to the saturation flow. Where the bus lane extends to the stopline, one lane of 'saturation flow' is lost to non-priority vehicles, with a consequent decrease in capacity and increase in delay to these vehicles. This is typical of the case at pelican type pedestrian signals within a link, where a setback is not provided. However, where the bus lane is terminated short of the stop line, i.e. when a 'setback' is provided, the saturation flow for non-priority traffic may remain unaltered, allowing the same number of vehicles to discharge during a saturated green period in both with and without bus lane situations. If the setback is too short, junction capacity will be reduced and non-priority traffic will suffer increased delays. Increase in delay due to a reduction of capacity is relatively small at low degrees of saturation but can be substantial at higher levels (e.g. as capacity is reduced close to or below demand), as described in Section 8.1. Too long a setback, on the other hand, results in buses suffering unnecessary additional delay. The length of the setback is therefore of crucial importance in determining the efficiency of the bus lane. The degree of use of the setback, termed the 'packing factor', is also of key importance in this respect. A full appraisal of setback distances and packing factors for the study sites is contained in Sections 7 and 8.

Roundabouts

The capacity of an approach to a roundabout depends mainly on the geometry of the roundabout (particularly of the approach in question) and the flow of circulating traffic (as this traffic has priority). The main geometric parameters controlling capacity are the approach and entry widths of the arm in question and the length over which a flare may be developed.

The effects of the introduction of a bus lane on the capacity of a link controlled by a roundabout is likely to depend largely on the setback of the bus lane, the degree to which this setback is used and the volume of circulating traffic. If the bus lane is continued to the give-way line, a queueing lane for non-priority traffic is lost and the capacity reduced, although buses gain maximum benefit. However, where a setback is provided such that the number of vehicles queueing in it is not less than the number which could accept the largest gap in the circulating traffic under prevailing conditions, the capacity for non-priority traffic is likely to be unaffected. Again, too long a setback will cause unnecessary additional delay to buses. Analyses of the effect of setback distance on roundabout capacity is further discussed in Section 7, results from the study sites being given in Section 8.

Priority Junctions

The effect of a bus lane on the capacity of a minor arm of a priority junction is likely to be similar to that described for roundabouts as both operate under 'gap seeking' conditions. The two key parameters affecting the capacity for non-priority traffic are therefore likely to be the volume of major road traffic and the length of the setback. The scale of the effects of these parameters will be somewhat different than at roundabouts however, as capacities are dissimilar and the 'secondary' effects influencing capacity are also different for the two junction types. The situation is likely to be rather more complex where two streams of major road traffic have to be crossed, but this condition is unlikely to occur in practice and was not witnessed during the site selection phase of this study. Priority junctions with long queues on a minor arm will normally either have been converted to a higher capacity layout (e.g. signals, roundabouts) or the minor road will have insufficient width for the provision of a bus lane.

Other Bottlenecks

While most bus lanes terminate close to a signal controlled junction or a roundabout, queues may form upstream of any 'bottleneck' where link capacity is reduced and a bus lane may be considered. A typical situation is where a dual lane link narrows to a single lane, perhaps due to the restriction of frontage development, a bridge crossing, etc. In this situation, where the number of available lanes is reduced by one due to a bottleneck, the introduction of a bus lane over the wider section may not reduce capacity at all, resulting only in a relocation of queues. In other cases, a bottleneck may occur further downstream, causing blocking back onto the bus lane link. In this situation, the effect of the bus lane on capacity for non-priority traffic may again be negligible if queueing behaviour is unaltered, although such blocking back may be an irregular occurrence and the provision of an optimum setback may still be desirable.

4.3 QUEUE LENGTHS

The queue length on a link is related to the traffic intensity at the 'critical point' on the link which is usually the downstream intersection. When a bus lane is introduced to allow buses to by-pass part or all of a queue, the *number* of non-priority vehicles queueing will not be affected provided the traffic intensity remains unaltered, (i.e. traffic demand and junction capacity remain constant). However, the queue *length* will increase as a potential queueing lane for non-priority vehicles will have been lost, i.e. the storage capacity on the link for non-priority vehicles has been reduced (assuming parking was restricted before the introduction of the bus lane). If traffic intensity remains constant, the increase in queue length will be equal to the number of vehicles which could have queued in the bus lane, ignoring any violations that may occur.

Possible consequences of an increase in queue length include increased use of alternative routes, change in delay to traffic entering from a side road and to 'cross traffic', and the blocking of upstream junctions. Where the queue extends upstream of the start of the bus lane, potential benefits to buses would also be adversely affected. Clearly these effects would be exacerbated if the bus lane caused a reduction in downstream junction capacity and consequential further increases in queue length. The assessment of these effects is discussed in Section 8.

SECTION FIVE

SITE SELECTION AND DATA COLLECTION

5.1 SITE SELECTION CRITERIA

The selection of sites for evaluation was based on the need to achieve both national coverage and a stratified sample to cover the wide variety of characteristics which occur in practice and which would be expected to feature in the evaluation procedure. An initial list of conurbations where bus lanes were known to exist was provided by T.R.R.L., and Local Authorities were then contacted for details of the location and characteristics of bus lanes under their control. Within the scope of the study it was decided to contact a representative cross-section of Local Authorities in the U.K. as shown in Section 11. The information and advice received from these Authorities proved invaluable and enabled an initial screening process to be undertaken prior to site visits. In total, some 110 with-flow and 22 contra-flow bus lanes were identified in these areas, most of which were visited prior to final selection.

The selection of a stratified sample was achieved after visits to each bus lane in each region during their period of peak traffic demand. A common survey form was used for this purpose for which information on the following key parameters was obtained:

- (i) Bus lane type and location
- (ii) Permitted users (as signed)
- (iii) Period of operation
- (iv) Link and bus lane lengths
- (v) Numbers of traffic lanes
- (vi) Priority and non-priority vehicle flows and levels of congestion
- (vii) Junction characteristics at the start and end of the bus lane
- (viii) Parking/loading restrictions and levels of likely abuse
- (ix) Pedestrian activity, including locations of pelican and/or zebra crossings
- (x) Frontage characteristics
- (xi) Numbers/locations of accesses/side roads and associated levels of flow
- (xii) Bus stop sitings and numbers
- (xiii) Diversion opportunities

Although this information was considered sufficiently comprehensive for site selection, it was only possible to visit each site for a relatively short period preventing thorough assessments of the sites being made during the full operational period. A key factor here was the level of traffic flow and congestion. Furthermore, some of the sites had to be visited during August and early September when traffic flows may have been lower than normal. Advice from Local Authority staff on 'typical' levels of traffic flow and congestion was particularly valuable in this respect.

The information obtained on the site information forms enabled each site to be classified into a number of key categories for final selection. The key categories comprised:

- bus lane length
- location
- method of downstream junction control
- flow of priority and non-priority vehicles
- 'level of friction'
- diversion characteristics for non-priority vehicles (contra-flow lanes only)

The 'level of friction' was a subjective assessment of the effect of a combination of factors which could reduce vehicle speeds on the link, such as those listed in items (viii) to (xii) above. Despite this subjectivity, a consistent assessment was adopted which was considered to adequately reflect these effects. A good range of the other important parameters, listed in (ii) to (vi) above, was achieved by ensuring a good regional cross section of sites, particularly in respect of conurbation size.

The location of each bus lane link was considered not only in terms of its regional location but also in terms of its position within a system. It was considered particularly important to include within the final sample a number of consecutive bus lane links as the benefits of a bus lane system comprising several connected links may not be the same as the sum of a series of 'isolated' links. In practice, it was necessary to restrict the surveys to not more than two consecutive links in a system to avoid biasing the overall sample towards a specific scheme which may have contained links with similar characteristics.

The numbers of contra-flow bus lanes in operation in the areas considered were only some 17% of the total number of bus lanes identified, and each system was unique in terms of layout, diversion requirements for non-priority vehicles, etc. The benefits predicted from each lane would therefore be system-specific and could not be applied more generally as may be the case for with-flow lanes. It was, therefore, not considered beneficial to include a large number of such sites in the final sample, but that more emphasis should be placed on deriving appropriate assessment methodology and procedures. A sample of 3 contra-flow sites were finally selected for appraisal spanning a wide range of layouts and traffic flows.

5.2 THE STUDY SITES

The bus lanes finally selected for study are listed in Table 5.1 which gives details of location, bus lane type, period of operation and the number of surveys conducted. The characteristics of these sites are detailed in Table 5.2 in terms of link/bus lane length, downstream junction type, number of traffic lanes, average traffic flows by vehicle type, average traffic intensity and an estimate of the degree of friction. It is considered that these sites represent a reasonable cross-section of bus lanes throughout the UK, excluding London.

5.3 DATA COLLECTION

Data collection requirements and procedures were determined and evaluated during August 1985, when a number of trial surveys were conducted. The information required to be recorded included:

(i) Classified turning counts of traffic at the downstream end of the link(s) and at any significant minor roads on the link. At priority junctions and roundabouts, major road (or circulating) flows were also recorded. At contra-flow sites, additional flow measurements were also taken at key junctions on the 'diversion' route for non-priority vehicles.

(ii) Journey times of priority and non-priority vehicles (recorded separately) over the section(s) of the bus lane link(s) in which priority vehicles could have an advantage. Pedal cycles would be excluded.

(iii) Signal timings, if applicable, sampled regularly throughout the survey period. For pelican signals, the frequency of call was also recorded.

(iv) 'Cruise' speeds of vehicles as they travelled down the link (obtained from measurements of free running journey times).

(v) Bus stopped times for each stop on the link.
(vi) Bus occupancies (car occupancies were also recorded at a number of sites).
(vii) Levels of traffic violations. This included details of stationary and moving non-priority vehicles illegally using the bus lane.
(viii) Any other site-specific factors that could affect the operation of the bus lane (e.g. exit blocking, pedestrian activity, etc.).

A further possible measurement of interest was saturation flow/capacity at the downstream junction. In the initial stages of the work, it was decided that saturation flows would not be measured on site but would be predicted from relationships recently developed at Southampton University[17], contained in Technical Paper 56[16], which were expected to provide a common base for evaluation. It was also anticipated that saturation flows may have to be varied somewhat to enable predicted and observed delays to be matched, a necessary step if realistic 'without bus lane' delays were then to be estimated. However, as the work progressed, it became clear that theoretical predictions were inappropriate in many cases where, for example, exit blocking was significant or variable use was being made of the setback. Appropriate measurements were therefore taken at a number of sites. These measurements were of saturation flow directly and/or queue lengths in each lane at the start of green, which gave an indication of packing factors i.e. the degree of use of the setback.

In addition to the traffic surveys, a full description of each site was recorded, including:

(i) Geometric details, such as bus lane and setback lengths, number/width of lanes, lane markings, etc.
(ii) The location and details of features such as bus stops, pedestrian facilities, waiting/loading restrictions, etc.
(iii) Photographs of the bus lane at several points along its length.

With peak traffic flows reduced in August, regular data collection was started in early September and was completed in early November. Surveys were undertaken on at least 2 separate days for each of the 25 sites, covering peak and off-peak periods where appropriate. Between-day variation was further assessed by carrying out additional surveys at one of the local bus lanes (site 03).

5.4 SURVEY PROCEDURES

The procedures adopted for the collection of much of the information described above were similar to those used in a number of recent studies at the University.

Classified turning counts were recorded in 5 minute intervals to allow fluctuations to be fully monitored. In practice, these flows were generally aggregated into 15 minute periods for subsequent analysis/modelling. The vehicle classes recorded separately were:

- Cars and light goods vehicles (3 or 4 wheels)
- Medium and heavy goods vehicles (> 4 wheels)
- Buses and coaches
- Taxis (if a priority vehicle)
- Motorcycles
- Pedal cycles

In addition to this classified turning count covering the whole survey period, the surveyor also noted signal timings at regular intervals, more frequent readings being taken at vehicle actuated signals where timings were more variable. At roundabouts, an unclassified count of circulating traffic was also made, by the same surveyor where possible.

Vehicle journey times were obtained by registration number matching, using Epson HX-20 portable computers as event recorders. The technique adopted was similar to that used successfully in other recent surveys undertaken for Hampshire County Council and T.R.R.L.[18,19]. The Epsons were synchronised before the start of each survey and the times that identified vehicles passed the start and end points of the test section(s) were recorded on a micro-cassette to the nearest tenth of a second. The data was subsequently loaded onto a larger computer for registration number matching, as described in Section 5.5.

With the high traffic flows at many sites, it was possible to record only a sample of vehicles. These were limited to those vehicles with specific digits at the start of their registration numbers. In general, numbers starting with a 1, 2 or 3 were chosen, which, allowing for some missed vehicles gave matched journey times for some 30% of the total traffic flow. Buses were identified separately by prefixing the digit 9 to the registration number, and a similar procedure using the digits 4 to 8 was available for identifying other priority vehicle classes as necessary. The registration numbers of all priority vehicles were noted.

This survey technique has been preferred for registration number surveys, as it results in an unbiased sample of matched vehicles, and the sample size can be controlled to match prevailing traffic conditions. Thus, where flows were lower an increased proportion of the traffic flow was recorded.

Where overtaking opportunities were minimal, only the first two digits of the registration number were recorded - this gave a reliable match as demonstrated in associated work[19]. At other sites, particularly those with contra-flow bus lanes, where substantial overtaking occurred in the non-priority vehicle streams, 3 digits were recorded to ensure reliable matching.

The distance over which buses could benefit from the bus lane, and therefore over which journey times were recorded was generally taken to be between the start of the bus lane and the stop line/give way line of the junction at the end of the link. This resulted in more variation in journey times, particularly for buses when flows were low (as, for example, a bus may have been delayed for a whole red phase in one period but not in another), or when bus stops were situated in the setback. However, the setback was rarely fully used by non-priority vehicles, giving buses an additional advantage in this area, as well as in the bus lane itself (assuming that it would have been used to a greater extent without the presence of a bus lane). This advantage would have been ignored if journey times were recorded only over the length of the bus lane. When queues extended upstream of the start of the bus lane, this was noted on site, but journey time measurements were still taken from the start of the bus lane as this was where buses usually started to benefit. (The effect of this build-up of queue was important, however, and was assessed during subsequent analyses.)

The Epson HX-20s proved reliable throughout the survey period, and very little data was lost through equipment problems. The dry weather conditions which prevailed during the autumn of 1985 were an additional advantage.

Cruise speeds were measured for a sample of unimpeded vehicles through the survey period by timing vehicles over a known distance.

Bus stopped times were measured as the time buses were actually stationary at the bus stop, an additional allowance for acceleration/ deceleration delays being made during the analyses. Where there were numerous bus stops on the link, it was not always possible to measure this parameter at each stop for each bus, and sample times were then taken so that information was obtained for each bus stop during part of the survey. In some cases buses were blocked by other buses in the priority lane whether or not they intended to set down or pick up passengers. These delays were noted by the surveyors and included in the bus stopped time in later analyses. Bus stopped times were particularly difficult to measure or interpret accurately where bus flows were high and clusters of bus stops were present.

Bus occupancies were estimated for each bus from observations either at bus stops or as the bus moved down the link. Occupancies of non-priority vehicles were also measured at a number of sites, typical sample sizes being around 100 vehicles.

The recording of traffic violations was undertaken by initially dividing the bus lane into 3 sections so that the approximate location of violations could be determined. All non-priority vehicles which used the bus lane were then noted as violation occurrences, both by time and location. Thus, the sections violated by a non-priority vehicle driving down the bus-lane were noted for each time period, and the duration and numbers of vehicles illegally parking/waiting were also noted for each section in each time period. More than one surveyor was required for these measurements at long bus lanes.

In addition to the 'standard' information described above, subjective records were also kept of other site specific factors of relevance. These included details of queueing behaviour, the extent and duration of downstream blocking when it influenced the normal discharge of vehicles from the link being surveyed and any other factors affecting the operation of the bus lane.

The surveys were carried out by a team of between 4 and 8 staff depending on the complexity of the bus lane system. Survey periods during peak conditions were chosen to cover the build-up and decline of the peak as well as the peak period itself. In general, peak and off-peak surveys covered 1½ hour and 1 hour periods respectively, although peak surveys were extended at some sites. Thus, morning peak surveys would typically be between 0730 hrs and 0900 hrs with off-peak surveys at those sites with 12 or 24 hour bus lanes being between 1000 and 1100 hrs. The evening peak survey window would typically be between 1630 hrs and 1800 hrs, with equivalent off-peak surveys between 1430 and 1530 hrs.

5.5 DATA PROCESSING

The main area of data processing concerned the calculation of vehicle journey times from the partial registration number data recorded on the Epsons. This processing sequence is illustrated in Figure 5.1. The data, which was stored on microcassettes was initially transferred onto a VAX 11/750 computer and edited for known errors. Where two or more Epsons had been used at a particular location due, for example, to high traffic flows, the data was merged to give one sequential data file for subsequent matching. Two data files were therefore compiled containing registration numbers and times for vehicles passing each end of the measured section. Vehicles were then matched in each file to obtain journey times.

The registration number matching program used was essentially that employed successfully on a concurrent study[19] for T.R.R.L., where journey times of vehicles on links were also required. The program considers perfect matches only (i.e. identical registration numbers) and requires a 'search window' to be specified within which the search for matches is restricted (i.e. journey times outside of a specified range are excluded). For the purpose of this study, separate windows were required for priority and non-priority vehicles, to cater for site specific variations between the two categories in levels of congestion, bus stopped times, etc. The lower limit of this window was relatively easy to determine by considering the maximum likely speed of vehicles over the link(s). The upper limit was less certain, however, being determined in practice by the degree of congestion on the link(s). If the upper limit was set too low, true matches would be excluded, whereas if it was too high, mismatches could result. However, there are well tested procedures within the program to limit the possibility of mismatches by, for example, considering the sequencing of vehicles at each end of the link. The likelihood of the window being inappropriate was assessed from a consideration of the journey times produced by the matching program after aggregation into (usually) 15 minute time periods. The window was suspect if:

- The standard deviation of the average journey times in any time period was abnormally high, indicating possible mismatches.
- The matching rate in any time period was abnormally low, indicating the possible exclusion of valid matches.

In these instances, the matching program was re-run using different window sizes until acceptable results were obtained. As a further check, limited manual matching was also performed for some of the data, particularly where there was some uncertainty.

In practice, matching rates in excess of 90% were common for priority vehicles, although for non-priority vehicles this rate could fall to around 70% at high flow multi-lane sites.

The final output from the registration number matching program gave the average journey times for priority and non-priority vehicles separately in specified time intervals. (The reference point was the time at which vehicles passed the downstream timing point.) After inspection of the results at a number of sites, a time interval of 15 minutes was chosen as standard. This was considered to be sufficiently small to reflect the variation in journey times through the peak, but generally large enough to allow reasonable values of bus journey times to be obtained.

Data processing of the other measurements described in Section 6.1 included:

(i) The manual aggregation of classified turning flows into 15 minute intervals compatible with the average journey time intervals,

(ii) The calculation of green and red signal timings, either as an average for the survey or, where times were variable, as an average for each 15 minute interval,

(iii) The calculation of average cruise speeds and their associated standard deviations,

(iv) The determination of average bus stopped time both per bus and per stop, for each time interval and for the whole survey period,

(v) The calculation of average bus and car occupancies,

(vi) An analysis of non-priority traffic violations.

TABLE 5.1 : SUMMARY OF SITES SURVEYED

SITE NO.	LOCATION	LINK	GRID REFERENCE*	BUS LANE TYPE	PERIOD OF OPERATION	NO. OF SURVEYS**
1	Southampton	New Rd.∇	SU 422 122	With-Flow	24 hrs	2p, 2op
2	Southampton	New Rd.∇	SU 424 123	With-Flow	24 hrs	2p, 2op
3	Southampton	Shirley Rd.	SU 407 129	With-Flow	0700-0930	5a
4	Portsmouth	London Rd.	SU 655 042	With-Flow	24 hrs	2p, 2op
5	Portsmouth	Milton Rd.	SU 633 003	With-Flow	24 hrs	2p, 2op
6	Oxford	Park End St.	SP 062 507	With-Flow	0700-1900	2p, 2op
7	Oxford	Botley Rd.	SP 062 499	With-Flow	0700-1900	2a, 2op
8	Bristol	Cheltenham Rd.∇	ST 741 591	With-Flow	0800-0915 &	2a
9	Bristol	Cheltenham Rd.∇	ST 743 591	With-Flow	1645-1800	2a
10	Cardiff	Dumfries Pl.	ST 768 185	With-Flow	24 hrs	2p, 2op
11	Leicester	London Rd.∇	SK 037 596	With-Flow	1600-1800	2p
12	Nottingham	Mansfield Rd.	SK 411 570	With-Flow	24 hrs	2a, 2op
13	Leicester	London Rd.∇	SK 036 598	With-Flow	1600-1800	2p
14	Derby	London Rd.	SK 357 356	With-Flow	1600-1800	2p
15	Derby	Curzon St.	SK 362 349	Contra-Flow	24 hrs	2a, 2op
16	Leeds	Roundhay Rd.	SE 359 320	With-Flow	0730-0930	2a
17	Leeds	Commercial Rd.	SE 356 262	With-Flow	1600-1830	2p
18	Leeds	York Rd.	SE 340 332	With-Flow	0730-0930	2a
19	Leeds	Dewsbury Rd.	SE 318 308	With-Flow	1600-1830	2p
20	Leeds	Chapeltown Rd.	SE 350 307	With-Flow	0730-0930	2a
21	Edinburgh	Princes St.	NT 738 250	With-Flow	1630-1800	2p
22	Edinburgh	London Rd.	NT 744 271	With-Flow	0800-0915	2a
23	Edinburgh	South Bridge	NT 735 260	With-Flow	1630-1800	2p
24	Southampton	Park St.	SU 398 138	Contra-Flow	24 hrs	2a, 2op
25	Reading	Kings Rd.	Su 722 734	Contra-Flow		2a, 2op

* of downstream intersection
** a = a.m. peak, p = p.m. peak, op = off-peak
∇ consecutive bus lanes

TABLE 5.2 : SUMMARY OF SITE CHARACTERISTICS

SITE NO.	LINK LENGTHS (M)			DOWNSTREAM JUNCTION TYPE[2]	NUMBER OF TRAFFIC LANES		TRAFFIC FLOWS[3] (VPH)			TRAFFIC INTENSITY (ρ)[4]	DEGREE OF FRICTION[5]
	TOTAL[1]	BUS LANE	SET-BACK		ALONGSIDE BUS LANE	AT STOP-LINE	BUSES	PEDAL CYCLES	OTHER TRAFFIC		
1	215	147	42	S	1	2	21	14	830	0.60	1
2	223	182	18	R	1/2	3	31	5	770	0.88	1
3	220	129	50	S	1	2	22	80	780	0.71	2
4	479	431	28	R	2	4	37	75	1875	1.05	2
5	335	266	54	R	1	3	11	9	770	0.98	2
6	215	163	37	S	2	3	21	185	705	0.99	4
7	1143	936	173	S	1	1	18	160	1000	1.20	3
8	169	88	56	S	1	2	31	155	1035	1.19	3
9	550	336	30	R	1	2	32	143	745	1.09	3
10	400	371	0	S	2/3	4	62	nr	1620	0.80	2
11	590	360	0	S	1/2	4	43	90	1490	0.63	3
12	430	395	31	S	2	3	78	60	1875	1.03	2
13	209	135	64	S	2	3	38	47	1245	0.93	3
14	402	365	31	R	1	2	15	42	800	0.99	3
15	262	168	0	S	0	1	11	15	580	0.91*	4
16	930	766	124	S	1	2	26	20	945	1.10	2
17	792	658	84	S	1	4	22	12	1355	0.97	2
18	660	482	37	S	2	4	60	nr	2830	1.03	2
19	515	336	73	S	1	2	34	16	715	0.50	3
20	1900	759	60	S	1	3	22	10	1180	0.89	3
21	213	213	0	S	2	3	100	29	650	0.44	4
22	309	163	75	S	1	3	64	nr	1140	0.88	3
23	214	184	10	S	1	2	96	52	595	0.50	3
24	222	58	0	S	0	1	12	11	80	0.64	2
25	1155	900	0	S	0	1	32	0	900	1.17	2

1 For contra-flow lanes, the total length for diverted non-priority traffic is given

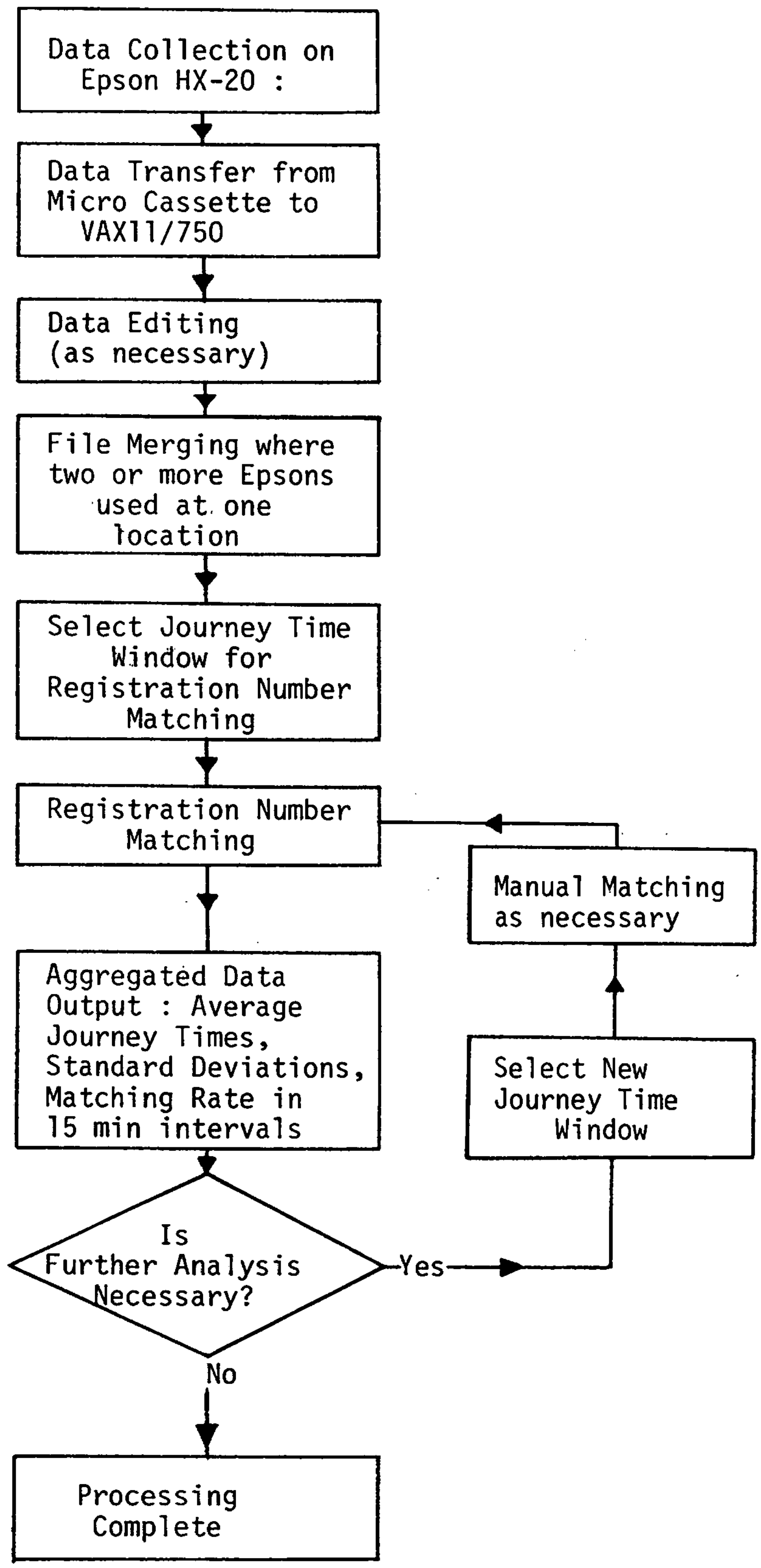
2 S = signals, R = roundabout (or priority junction)

3 Flows are the average from the peak period surveys
nr = not recorded

4 This is the average traffic intensity for the peak hour (total traffic demand divided by downstream junction capacity as determined during the modelling (see Section 7)). (Some intervals within this peak hour would have had higher intensities). Values marked * refer to non-priority traffic at contra-flow sites.

5 Friction is subjectively rated from 1 to 4 (low to high) and incorporates such factors as the degree of parking/loading, pedestrian and frontage activity, road alignment (e.g. lane widths, curvature, etc.), numbers/use of bus stops, proportion of pedal cyclists, etc.

FIGURE 5.1 : DATA PROCESSING FLOW CHART



SECTION SIX

SURVEY RESULTS

The results of the surveys carried out at the 25 bus lanes are described in detail in the Data Base Appendix (Appendix A), which also contains full geometric details and associated information. (Summaries of these sites and their main characteristics are given in Tables 5.1 and 5.2.) The Appendix contains details of traffic flows and journey times for the different surveys at each site, as well as summary tables of such factors as average vehicle occupancies, average stopped time for buses at bus stops and the degree of illegal use of the bus lane. Also included in this Appendix is a general description of each site with subjective comments describing its operation: these comments are expanded in the following sections. It has not been attempted either in this Appendix or in this Section to judge which bus lanes are operating efficiently and which are not. It is felt that this is largely related to the alternative mode of operation without the bus lane, and comments in this area have therefore been included in Sections 8 and 9, albeit with the associated uncertainty of predictions rather than observations of alternative conditions. The survey results described below are related to the potential impacts described in Section 3.

6.1 JOURNEY TIMES

The average journey times for priority and non-priority vehicles recorded in each survey are given in Table 6.1. The journey times for priority vehicles exclude the average time spent at bus stops and an estimate of the deceleration and acceleration delay associated with the stops. (An average acceleration/deceleration rate of $1m/sec^2$ was used in these calculations, giving a typical acceleration/deceleration delay of 10 secs in total, which is compatible with that used in the T.R.R.L. simulation studies.) The exclusion of time associated with bus stops allowed a better comparison to be made between observed journey times and those predicted by the traffic models, which could not incorporate these effects.

Also included in Table 6.1 are the measured differences in journey times between priority and non-priority vehicles and whether or not these differences are statistically significant (@ the 5% level). (The significance calculations were based on the level and variation in average journey time differences in 15 minute intervals throughout the whole survey period although a more detailed breakdown could be obtained by comparing intervals within a survey period. Information for such an analysis is given in the Data Base Appendix.)

Variations in measured journey time differences between priority and non-priority vehicles were found to be largely related to the level of traffic intensity (traffic demand/junction capacity), as illustrated in Figure 6.1. Thus, increasing levels of traffic intensity cause increased queue lengths which in turn lead to longer journey times for non-priority vehicles. Priority vehicles, on the other hand, are able to overtake any queue which is longer than the setback distance (provided it is shorter than the bus lane length) and are thus subject to a maximum junction delay which is related to the setback distance and the entry capacity. This is reflected in the graphs of average journey time for buses against that for other vehicles given for each site in Appendix A. Other factors affecting the measured journey time differences between priority and non-priority vehicles were the bus lane length, which largely controlled the maximum level of these differences and the discharge rate for traffic leaving the bus lane link: For any set number of non-priority vehicles overtaken by buses, the lower the discharge rate the greater the journey time difference between the two categories of vehicles, as illustrated in the theoretical examples in Figure 6.2.

The measured difference in journey time between priority and non-priority vehicles can be seen to be insignificant or negative at a number of sites (Table 6.1). Insignificant differences usually occurred at sites where non-priority traffic queue lengths only infrequently exceeded the setback distance. This was common at all sites in off-peak periods but also occurred during peak periods at sites 1, 3, 13, 19 and 22 and, to a lesser extent, at sites 17 and 20. At other sites where negative differences occurred, this implied a lower running speed for buses than for non-priority vehicles which could occur where, for example, bus flows and/or bus stop densities were high (e.g. sites 21, 22, 23) or other factors predominated (e.g. parking violations at site 11, and an uphill gradient at site 12). Further discussion of bus running speeds is contained in Section 8.4.4.

Also included in Table 6.1 are the average peak hour traffic flows for buses, pedal cycles and other traffic.

6.2 MAXIMUM 'WITHOUT' BUS LANE JOURNEY TIMES

The journey time and traffic flow results in Table 6.1 can be used to determine the maximum 'without' bus lane journey times for the with-flow bus lanes which in turn lead to estimates of their maximum benefit. The method involved is based on the assumption that the bus lane causes no additional journey time to non-priority traffic other than through the overtaking effect of priority vehicles. (In the extreme situation where a stream of traffic contains no priority vehicles it is assumed that the bus lane has no effect on vehicle journey times.) The conditions when this may apply include:

- Where an optimum setback is provided which is expected to be fully used. Entry capacity would then be unaffected by the bus lane.
- Where exit blocking is controlling the discharge rate from the link (although this may be variable and needs careful consideration).
- Where an exit constriction controls queueing behaviour (i.e. the link capacity at the constriction is less than that at the stop line of the bus lane link).

In these circumstances, and provided there are no other factors associated with the bus lane which would increase journey times for non-priority traffic (see section 6.5), it may be assumed that the bus lane re-distributes delays between priority and non-priority vehicles but that the aggregate delay remains unaltered. This is represented by the equation:

$$T_a q_a = T_p q_p + T_{np} q_{np} \qquad \text{...... 6.1}$$

Where T_a = average journey time for all vehicles without the priority

T_p = average journey time for priority vehicles with the priority

T_{np} = average journey time for non-priority vehicles with the priority

q_a = total flow

q_p = flow of priority vehicles

q_{np} = flow of non-priority vehicles

This equation uses the approximation that all vehicles have the same journey time without the bus lane, i.e. bus stopped times and associated effects are excluded, and that traffic flows are the same with and without the bus lane. Traffic flows should be expressed in passenger car units (pcus) to allow traffic flows with different vehicle compositions to be expressed in equivalent units. The most recently measured pcu factors at signal controlled junction entries[17] are :

Cars/light goods vehicles (3 or 4 wheels)	: pcu factor = 1
Medium goods vehicles (> 4 wheels; 2 axles)	: pcu factor = 1.5
Heavy goods vehicles (> 2 axles)	: pcu factor = 2.3
Buses/coaches	: pcu factor = 2.0
Motorcycles	: pcu factor = 0.4
Pedal cycles	: pcu factor = 0.2

The main importance of pcu factors in this context is that, when a bus overtakes a queue of non-priority traffic it effectively 'displaces' 2 passenger cars (as its pcu factor is 2.0). The additional journey time to non-priority traffic therefore depends on both the flow and types of vehicles using the bus lane. (If flows were expressed in vehicles, however, only the flow itself would be significant; non-priority traffic would then be predicted to suffer the same additional journey time regardless of the vehicle type overtaking them (e.g. buses or pedal cyclists) which is not realistic.) In practice, the pcu concept means than, if cars with a pcu factor of 1 have an average occupancy of say, 1.5, buses, with a pcu factor of 2 need an occupancy of more than 3 to produce an overall passenger time saving with a bus lane.

An example of the use of equation 6.1 applied to 'with' bus lane data to predict 'without' bus lane journey time is given below :

Priority traffic flow (q_p)	= 100 pcu/hr (e.g. 50 buses/hr)
Non-priority traffic flow (q_{np})	= 900 pcu/hr
Priority vehicle journey time (T_p)	= 100 seconds
Non-priority vehicle journey time (T_{np})	= 200 seconds

Then from equation 6.1 $T_a \times 1000 = (100 \times 100) + (200 \times 900)$

and $T_a = 190$ seconds

Thus, in this example, priority vehicles save 90 seconds of journey time on average and non-priority vehicles lose 10 seconds on average.

This procedure has been applied to each set of survey results listed in Table 6.1 to enable the maximum economic benefit of each bus lane to be determined (as described in Section 9). Where none of the conditions listed above applied (i.e. the bus lane was considered to adversely affect capacity, as listed in Table 8.3) the effects of the bus lane on journey times were predicted from computer modelling, as described in Sections 7 and 8. The use of pcu's is consistent with the modelling methods adopted in these sections, where the total traffic flow on the bus lane link was specified in pcu's and the benefits to buses calculated externally depending on queue length (in pcu's) and the link discharge rate (in pcu/hr). When modelling the without bus lane situation, the delay per pcu is the same as the delay per vehicle (which is the unit usually output by traffic models) assuming vehicles of different types are randomly positioned in the traffic stream.

Equation 6.1 can also be used for calculating the maximum benefit of a proposed bus lane, as illustrated in the example in Appendix F. In this case, measurements can be taken of all parameters in equation 6.1 except T_p and T_{np}. One method of estimating T_p is by deducting from T_a the time taken for a vehicle joining the back of the queue to reach the end of the bus lane, including allowances as necessary for the packing factor, bus lane violations, etc. as described later in this Section. This measurement which gives an indication of the time buses would save through avoiding this queue would need recording on representative occasions during the period of interest. (It is also necessary to measure queue lengths to assess whether they will extend upstream of the start of the bus lane.) An alternative but similar method is to use a measured relationship between journey time and queue length, as illustrated in Appendix F. The estimate for T_p then allows a value of T_{np} to be obtained from equation 6.1 and the overall effect of the bus lane to be estimated.

Other non-modelling methods which may be used to estimate junction delays and the effect of a setback on these delays are described in Appendix C.

6.3 SETBACK DISTANCES

Setback distances varied considerably between sites for the with-flow bus lanes (as shown in Table 5.2), and it was suspected that some of the shorter setbacks may have been causing a loss of junction capacity for the signal timings in operation during the surveys. The extent to which this was occurring was initially analysed theoretically, the results being given in Table 6.2. In this analysis sites with no setback have been excluded and those where the nearside lane in the setback was restricted to left turn only traffic are separately identified. Table 6.2 gives details of the measured setback, the optimum setback according to H6/76[5] (i.e. twice the effective green time in metres) and the optimum setback for fully saturated conditions based on the predicted saturation flow[17] and a queued vehicle headway of 5.5m as found in recent surveys[19]. The latter calculation is explained beneath Table 6.2 and is based on the 'saturation flow profile' concept illustrated in Figure 7.3.

For setbacks where the nearside lane is restricted to left turn only traffic, shorter setbacks can be used related to the average number of left turning vehicles arriving per cycle. However, longer setbacks may not significantly disbenefit buses in this situation as only left turning vehicles would use the nearside lane in the setback regardless of its length. Left turn only lanes are common at internal junctions within bus lane systems, and inevitably lead to a loss in junction capacity as through traffic loses the use of the nearside lane.

Also included in Table 6.2 is the predicted effect of the bus lanes on roundabout entry capacity at the 5 roundabout entries concerned. These results are based on the use of current roundabout entry capacity formulae[23] where the setback is taken to be equivalent to an entry flare. There are no comparable optimum setback recommendations for roundabouts given in H6/76, although advice is given that "it will probably be in the range 10-50m".

The points of note in Table 6.2 are:

(i) Many setbacks appear theoretically to be too short for the signal timings in operation, causing a loss in junction capacity.

(ii) 'Optimum' setback distances based on recommendations in H6/76 can lead to a loss in theoretical entry capacity. For example, a loss of around 14% has been calculated for two lane entries, reducing to around 7% for four lane entries using the method described in Section 7.1.1. To ensure no loss in entry capacity a setback distance of around 2.7 times the effective green time is required, assuming saturation flows of 1800 pcu/hr/lane and queueing headways of 5.5m.

It must be strongly emphasised that these results refer to 'ideal' conditions where entry capacity can be achieved. This was not the case at many of the sites studied, where setbacks were not fully used due to factors such as poor exit alignment and exit blocking. At site 8, for example, the setback was theoretically too short but was hardly used due to constriction on the main downstream link - in these circumstances, an even shorter setback would have been justifiable. The main problem at a number of such sites was deciding whether more use would have been made of the nearside lane at the junction entry were the bus lane removed. Clearly, this information could be obtained prior to implementation of a bus lane, and the optimum setback would be best determined by on-site observation.

A further key point is the relationship between setback distances and signal timings. Many of the bus lanes were introduced up to a decade ago and it is likely that changes in signal timings/forms of control in the intervening period have occurred but have not been matched by a 're-optimisation' of setback distances. It is clearly important for signal timings to be compatible with setback distances 'on-street' if maximum entry capacity is to be maintained.

6.4 'PACKING' FACTORS

A further potential cause of a loss in junction capacity due to a bus lane is that drivers may not fully use the nearside lane in the setback. This was assessed on site by noting the queue length in this lane on regular occasions when the queue in the offside lane(s) exceeded the setback distance. The ratio of the actual queue in the nearside lane to that which could have formed gave the 'packing factors'. Average packing factors recorded at the survey sites are given in Table 6.3. This Table excludes all sites where the nearside lane in the setback was restricted to left turn only vehicles, but includes roundabout entries. Lane direction markings were not evident at the roundabout entries but lane choice/use is clearly related to the turning movements involved. Thus, at sites 4 and 14, for example, the apparent low use of the setback could have been caused by the high proportion of right turning traffic rather than by the presence of the bus lane. It is also likely at roundabout entries that queueing behaviour reflects the width and alignment of the circulating carriageway. Where a bus lane leading into a roundabout is proposed, observations of existing queueing behaviour are clearly of importance if an optimum design is to be achieved.

It is clear from this Table that packing factors were often less than one, and there is evidence to suggest that they decrease as setback lengths decrease. However, deriving a significant relationship of this form has not been possible from the limited data available.

Also included in Table 6.3 is the effect of these packing factors on predicted maximum saturation flows (see Section 6.3), giving new lower values in most cases. These new values are also compared with those calibrated with CONTRAM (see Section 8.2.1) and are seen to be generally much closer than the original predictions.

6.5 OTHER RESULTS/COMMENTS

6.5.1 Operational Characteristics

6.5.1.1 Pedestrian Crossings

The effects of introducing a bus lane on a link containing one or more pelican crossings depends largely on the frequency of use of the pelican crossing and the extent to which the loss of a lane for non-priority traffic becomes critical. At most sites, the critical point in terms of capacity will be the junction at the end of the bus lane rather than a pelican crossing. Benefits/disbenefits to priority and non-priority vehicles due to the pelican will therefore be low. This situation was observed at sites 4, 9, 11, 18, 19 and 21. However, there are circumstances where the pelican crossing(s) become critical, as observed for example at site 20, where only one lane was available for non-priority traffic and the pelicans were operating at or near capacity. This was also resulting in some cases in there being insufficient demand to fill the setback, even though the green time was only 17 secs within a cycle time of 60 seconds. Buses therefore benefitted mainly at the pelicans, equal or greater disbenefits occurring to non-priority vehicles being predicted in the modelling (see Section 8.3). (This assumes that two lanes could have been used before the introduction of the bus lane).

The effect of zebra crossings on traffic performance was generally less than that of pelicans, as pedestrian flows were usually lower and pedestrians were observed to either wait until a suitable gap in the traffic occurred, or were able to cross between stationery queueing vehicles, causing no additional delay.

No obvious disbenefits to pedestrians due to a bus lane were noted at any of the study sites.

6.5.1.2 Flared Entries

A technique adopted in recent years for increasing the capacity of junction entries has been to flare the approach (e.g. as illustrated in Figure 7.3). Flares are particularly common at roundabout entries and their treatment is discussed in Section 7. At the signal controlled junctions surveyed in this study, sites 17 and 20 both had flared approaches. Site 20 has been discussed above with relation to pelican crossings, but a similar situation also applied to Site 17, in that the capacity of the lane adjacent to the bus lane appeared more critical than that of the downstream junction entry, where a generous flare was provided (4 lanes were available at the stop line). Again, the supply of vehicles from this lane was sometimes insufficient to fill the setback area even though a long queue existed upstream, and appropriate signal timings were clearly crucial (e.g. the timings should be such that all vehicles in the setback can discharge in a green period, but the red period should be sufficient to allow the setback to be refilled). Different signal timings were recorded at this site on two survey days, the lower green times on day 2 (which were more appropriate to the flared setback area) producing delays to non-priority vehicles similar to those on day 1 despite the reduction in the proportion of green time available to the approach. (Other approaches to the junction would have benefitted on day 2 through the increased amount of green time available to them.)

6.5.1.3 Right Turning Traffic

Where right turning traffic is subject to opposing flow at a junction, and a dedicated right turning lane is not provided, queueing and lane choice behaviour can be complex. A key factor is the probability of a queue in the offside lane exceeding the setback distance, as, if this occurs, a significant loss in junction capacity may result, due to following through traffic becoming impeded by right turning vehicles and not being able to use the nearside lane without violating the bus lane.

It was noticeable that, at sites without a dedicated right turning lane, the right turn movement had been banned at all but two of the study sites (site nos. 3 and 8). At these sites, the proportion of right turners was too low to have a significant impact on through traffic.

Impedence to through traffic was also observed at a number of sites on the bus lane link due to traffic turning right into side roads and other accesses and being delayed by oncoming vehicles (e.g. at sites 5, 7, 9, 14, 17 and 20). This was most noticeable at sites with only one lane available for non-priority traffic adjacent to the bus lane. It was observed that the majority of through traffic locally violated the bus lane under these circumstances, and their extra delay was therefore low and could not be adequately quantified. (Such quantification would have required the modelling of each significant right turning movement, but meaningful results would not be likely to be achieved due to the variations in local violation behaviour.)

6.5.1.4 Pedal Cycles

One of the possible factors which may cause a reduction in bus running speeds in a bus lane is the presence of significant numbers of pedal cycles. This possibility has therefore been investigated at the study sites. There are a number of problems with separately identifying the effects of pedal cycles as bus running speeds may be affected by a range of other factors such as bus lane width, queueing characteristics of non-priority vehicles in the adjacent lane(s) and bus stops. Also, the measurements of journey times in this study (from which speeds were derived) were generally taken between the start of the bus lane and the downstream junction stop line, so these times incorporated variations in junction delay that occurred during the peak, thus further masking possible effects of pedal cycles.

An investigation of the relationship between bus journey speeds averaged over 15 minute intervals and equivalent pedal cycle flows was carried out at four sites which had noticeably higher proportions of pedal cycles (more than 100 per hour). The only site where a statistically significant relationship was found was site 9, as illustrated in Figure 6.3. This site, which had a standard 3.0m wide bus lane, had the following characteristics when surveyed.

- Near continuous queueing of non-priority vehicles in the adjacent lane
- Little use of the short setback (30m) by non-priority vehicles
- Insignificant effect of bus stops

These conditions should be suitable for assessing the effects of pedal cycles as buses could not easily overtake them (there being an adjacent queue) and recorded journey times were largely free from junction delays. (Other possible effects on bus journey speeds, such as the level of non-priority traffic flow, were assessed but found to be insignificant).

The best linear relationship in Figure 6.3 was

$$V_b = 27.7 - 0.07q_p \ (r = -0.70) \qquad \ldots\ldots\ldots 6.2$$

where V_b = average speed of buses (kph)
q_p = pedal cycle flow (cycles/hr) for $80 < q_p > 200$

Clearly this relationship is site specific, the constant in particular reflecting the specific road type and incorporating small elements of bus stopped time and junction delay. However, the rate of reduction in bus speeds with increasing pedal cycle flow of 7 kph per 100 pedal cycles may give an order of magnitude effect for similar conditions elsewhere.

6.5.1.5 Traffic Violations

Violation of a bus lane by non-priority vehicles can have an adverse effect on the efficient operation of the bus lane: Vehicles illegally stopped/parked in the bus lane can cause extra delay to buses as they have to pull out into the non-priority traffic stream, which may be stationary. Moving violations can also cause additional delay to buses, particularly if they cause the nearside lane queue to extend into the bus lane.

<u>Parked Vehicles</u>

Journey time savings for priority vehicles due to the introduction of a bus lane are usually gained through overtaking queues of other traffic. However, savings can also occur if the bus lane results in reduced levels of parking/loading, with or without increased parking restrictions. The extent to which the presence of a bus lane reduced parking/loading violations at the study sites is unknown, and would normally have to be assessed through 'before and after' studies. In the evaluation of these sites, it has been assumed that parking characteristics were similar before and after the introduction of the bus lane, so that the benefits/disbenefits predicted are due to the bus lane alone. However, this simplification may not be sufficient at proposed sites where parking violations are currently significant or where new restrictions are required, and a careful assessment of likely parking characteristics and their effects may be necessary.

While this assessment has to be site specific, it may be helped by a consideration of the extent to which non-priority vehicles stopped or parked in the bus lanes surveyed, as given in Table 6.4. Where these violations occurred, one or two vehicles only were usually involved with the exception of site 11, where parking was permitted during off-peak periods and a number of vehicles remained parked during the operational period of the bus lane (1600-1800 hrs). This effectively prevented buses using the bus lane to any extent, although, with delays being low on the link when surveyed, the bus lane would only have offered a marginal saving to buses if operating satisfactorily. This bus lane link borders shops and offices, which encourage parking, and would appear to require frequent police enforcement of the parking regulations. The other main 'problem' link was site 6, a 12 hour bus lane, which fronted premises where loading/unloading was a frequent occurrence, particularly during business hours (i.e. mainly the off-peak period). The benefit of the bus lane during off-peak periods in particular was therefore reduced whenever queued non-priority vehicles in adjacent lanes prevented buses from easily overtaking those stopped in the bus lane. Such queues were not prevalent in the off-peak surveys however.

The effect of parked vehicles on the operation of the bus lane could not be accurately quantified from the data collected during the surveys as serious violations occurred at only two sites. However, some indication of the possible effect of illegal parking on the running speeds of buses is given in Table 8.8 although other factors listed in Table 8.8 may also have been significant.

If frequent parking/loading is likely in a bus lane, due to such factors as frontage activity a lack of rear service roads, delivery accesses or other parking facilities, a bus lane may well be inappropriate. Regular costly police enforcement is unlikely to be a satisfactory option.

Moving Violations

The numbers of non-priority vehicles violating each bus lane (normally to avoid queues in the lane(s) adjacent to the bus lane) were measured during the surveys. The percentage of such traffic in 15 minute intervals for each survey is given in Appendix A - Data Base. These percentages refer to vehicles which violated at least the downstream half of the bus lane. 'Temporary' violations at the start and end of the bus lane, or as caused by right turning vehicles stopped in the non-priority lane, have therefore been excluded. A summary of the proportion of moving violations for each site is given in Table 6.5. The average for all peak surveys was 4% which is lower than has been recorded elsewhere (e.g. Reference 12 reports violation rates ranging from 5% to 15%).

The effect of moving violations on the operation of the bus lane depends mainly on whether the use of the setback is altered. (It is unlikely that violators will significantly reduce the speed of buses in the bus lane, as such drivers are likely to be more aggressive.) Where the proportion of violations is low, these vehicles are likely to use the nearside lane of the setback in place of other non-priority vehicles. Buses are not then affected. However, if the proportion of violators is high enough to increase the use of this nearside lane, perhaps causing a queue to build back into the bus lane, buses will be adversely affected. Conversely, this behaviour may lead to an increase in junction capacity and reduced delay not only to violators themselves (which may be undesirable) but to non-priority traffic as a whole.

The proportion of moving violations may be expected to increase as the delay (or queue length) for non-priority traffic increases. This was investigated for the survey sites by plotting the proportion of such violations against measured delay per km of bus lane for non-priority traffic, based on average 15 minute observations. (Delay/km was found to be a better descriptor than delay itself.) The resulting relationship is illustrated in Figure 6.4 and the following regression equation was derived:

$$V = 0.02D - 0.5 \quad (r = 0.77) \qquad \ldots\ldots\ldots\ldots \quad 6.3$$

where V = percentage of moving violations
D = average delay (secs/veh) for non-priority traffic per km of bus lane

This equation could be used for predicting whether setback usage is likely to be affected by moving violations, allowing junction capacities and journey times to be re-assessed accordingly (n.b. if only the queue length is known/estimated, delay can be calculated as the average number of vehicles in the queue divided by the discharge rate).

6.5.1.6 Bus 'Cruise' Speeds

The average speed for buses at each site inferred from the journey time measurements given in Table 6.1 include the time associated with junction delays which mask the effect of the bus lanes on bus cruise speeds. A clearer analysis of bus cruise speeds has therefore been undertaken by relating estimates of these speeds (based on the exclusion of predicted junction delays) to features of each bus lane link (e.g. degree of parking violations, frequency of bus stops, etc). The results are partly based on delay predictions from the modelling, and are therefore described in Section 8.4.4.

6.5.1.7 Bus Stops

Apart from the potential benefits of re-siting bus stop to reduce walking time, particularly in relation to contra-flow bus lanes, two further aspects of bus stop siting have arisen during the study:

(i) Bus stops sited immediately downstream on the exit of a bus lane link (e.g. at sites 12 and 13) cause an exit constriction and consequent loss in junction capacity when a bus is stationary at the bus stop. Such bus stops may also result in a reluctance of drivers to use the nearside lane in the setback (if available) and a further loss of capacity. In these circumstances, it may be beneficial to re-site the bus stop either further downstream away from the junction or upstream at the end of the bus lane.

(ii) Where a bus stop could be sited either in the setback or at the downstream end of a bus lane, the latter location may be preferable to avoid a reduction in junction capacity. If the bus stop is sited in the setback, capacity will be reduced whenever a bus is stopped and the approach is discharging. Drivers may also be reluctant to fully use a setback containing a bus stop even if the stop is vacant. The benefit to buses through siting a bus stop in the setback may be insignificant, particularly if they cannot reach the stop until traffic is discharging.

6.5.1.8 Forms of Signal Control

Optimum setback distances are related to the effective green time on an approach and, where this varies due to a traffic responsive form of signal control (e.g. vehicle actuation or SCOOT) or to more than one fixed time plan being in operation, the setback distance on street cannot be optimum under all conditions. Vehicle actuated signals controlled around 25% of the junctions surveyed. During periods of significant queueing when the bus lanes had greatest effect, these signals generally operated to a preset maximum green time, thus operating similarly to fixed time signals. The occasions when they 'gapped out' (i.e. changed to red early because of a significant gap in the traffic - perhaps caused by a vehicle stalling) were few, and, in the absence of other factors, such as exit blocking, a setback distance related to the maximum green time would be appropriate.

Only one of the with-flow bus lanes surveyed operated under SCOOT control although this system is becoming increasingly common in urban areas. Bus lanes are likely to be less compatible with SCOOT control than with alternatives as, even under conditions of high traffic intensity, signal timings change to reflect traffic conditions not only on the bus lane link but also on competing links at the junction and even at junctions elsewhere in the network. A setback distance related to the maximum likely green time may be necessary to avoid a loss of junction capacity but this will result in very long setbacks and diminish the benefits of the bus lane to buses on many occasions. It may also be more difficult to maintain efficient traffic progressions on a link containing a bus lane.

There is clearly a need for further research in the area of bus priority with traffic responsive forms of control.

6.5.1.9 Other Effects on Non-Priority Traffic

Blocking Back

Non-priority traffic was observed to queue back through at least one main upstream junction for part of the peak period at four of the sites surveyed (site nos. 6, 7, 8 and 9). These bus lane links varied in their length from 169m to 1143m. This blocking back was clearly partly caused by the bus lane in each case, due to the loss in potential queueing space. The majority of vehicles on upstream links affected by the blocking back subsequently used the bus lane link and the blocking back itself may not have significantly affected their journey times. However, traffic on upstream links which had alternative destinations would have been adversely affected. While such effects have not been quantified in this study due to a lack of appropriate data, these effects would normally have to be considered in a thorough evaluation.

Oncoming Traffic

With-flow bus lanes are usually installed on roads having 4 or more lanes - where there are less than 4 lanes H6/76 states that 'a with-flow bus lane in one direction is practical provided that it can be ensured that buses moving in the opposite direction will not be adversely affected. For instance, they could be unable to overtake parked servicing vehicles because of the concentrated flow or queue of traffic in the adjoining opposing lane.' At a number of the study sites, two lanes were not marked for oncoming traffic but the road width was sufficient to allow overtaking. Such sites were 3, 7, 8, 9, 16, 17, 19 and 20. At site 5 however the available road width for oncoming traffic was only of the order of 3.8m. The main observed effect of this was that, when oncoming buses stopped at bus stops, following traffic was, on occasions, unable to overtake due to a queue in the lane adjacent to the bus lane. Thus, oncoming general traffic was affected rather than buses. (Parking restrictions were observed on this link.) The provision of bus bays would normally alleviate this effect although restricted space prevented this on this link.

Re-Assignment

Possible traffic re-assignment to alternative routes due to increased queues and (possibly) delays on the with-flow bus lane links could not be adequately assessed in the course of this study. Such an analysis would require a knowledge of 'normal' traffic volumes on alternative routes before the introduction of the bus lane, and, as most of the bus lanes were introduced some years ago, reliable figures were not available. (This would not normally be a problem for new schemes however.)

Maximum delays at most sites were usually less than 5 minutes per vehicle despite the presence of long queues on occasions and it is likely that local re-assignment onto minor roads would not be perceived to be worthwhile, with the usual difficulties in having to rejoin the congested major road.

Of the 22 with-flow bus lanes surveyed, it is thought that traffic re-assignment as a result of the bus lane could have been significant at only 4 : At sites 8 and 9, queues sometimes extended up Cheltenham Road as far as its junction with Zetland Road, and it is likely that some traffic diverted to Arley Hill or Sydenham Road. At site 14, right turning traffic volumes were noted to increase by up to 100% into Midland Road and/or Canal Street when queues on the bus lane link reached these locations, presumably to avoid these queues. At site 7, inbound queues stretched for well over 1km on occasions, and although no local re-assignment was practical due to the river crossings, some re-assignment on a wider scale onto other main radial routes could have occurred due to the bus lane.

6.5.1.10 Between Day Variations

Variation in journey times and associated parameters between days is likely to be substantial at most bus lane sites operating at or near capacity. Sensitivity tests have shown that, under these conditions, journey times are very sensitive to small changes in demand or capacity, which may occur due to such factors as environmental conditions, seasonal variations or traffic incidents (e.g. Figure 8.1).

Between day variations in journey time recorded at the study sites (e.g. as in Table 6.1) were generally restricted to information from two (usually consecutive) days when environmental conditions were favourable. Even then, some variation was observed between days (e.g. sites 4, 6 and 9). A more detailed investigation of such variations was carried out at site 3 in Southampton, where data was collected on 5 days spaced throughout the survey period. This site was generally operating below capacity however, and journey times were relatively low and consistent between days (see Table 8.1).

The extension of the results obtained from two days of survey to estimate annual benefits is clearly uncertain - it is particularly likely that, on at least a few days a year, considerable congestion would occur at a bus lane site for various reasons unconnected with the bus lane. However, it is considered unrealistic to attempt to quantify this effect, as it is by no means certain that buses would enjoy an increased benefit in this situation; they may be delayed in upstream congestion which may be unrelated to the bus lane, bus lane violations may increase and a number of secondary effects are likely. For these reasons, it has been decided simply to estimate annual benefits/ disbenefits for each site directly from the information available.

In general, it is not practicable to carry out traffic surveys on a large number of days covering all the variations in traffic flows that can occur due to time related (e.g. daily, weekly, seasonal) and environmental effects. A better approach would be to undertake a series of sensitivity tests in the modelling to assess the likely effects of these variations. For example, time dependent variations in traffic demand will normally be known from traffic counts or from adjacent UTC installations, while information on saturation flow variations has been reported elsewhere[17] (e.g. an average decrease in saturation flows at traffic signals of some 6% has been recorded between dry and wet road surface conditions[17]). The best approach may be to model average and extreme (e.g. maximum demand/minimum saturation flow) conditions and determine the level of analysis required from the difference between these two sets of results.

6.5.2 Control Characteristics

6.5.2.1 Operational Periods

The operational periods of the bus lanes surveyed in this study are listed in Table 5.1. The three alternative operational periods recommended in H6/76 are represented - peak hours only, 12 hour and 24 hour operation although, of the sites considered, 12 hour bus lanes were only found in Oxford. Although operational periods varied considerably between conurbations (e.g. 55% of the with-flow bus lanes studied operated during peak hours only), there was general consistency within an area. This leads to less confusion for drivers and easier enforcement and follows the recommendations given in H6/76.

Operational periods in peak hours varied between 1¼ hours at some bus lanes in Bristol and Edinburgh, to 2½ hours at some sites in Southampton and Leeds. These operating periods may be expected to reflect the time when congestion occurs with an additional allowance of say ½ hr either side of this period to minimise the effect of parked vehicles departing late or arriving early, as recommended in H6/76. (This additional one hour has clearly not been implemented at the sites in Bristol and Edinburgh.) Many of the bus lanes were introduced up to ten years ago and operational periods fixed at that time may not be optimum for current traffic conditions.

The advantages and disadvantages of the alternative operating periods are set out in H6/76. From our surveys it was found that the bus lanes had greatest effect on journey times during peak periods, as would be expected with the higher levels of traffic intensity. However, noticeable effects were recorded during off-peak periods at some of the 12 or 24 hour bus lanes (e.g. sites 4 and 10) which were significant when aggregated. Where a bus lane is implemented which causes no disbenefit to general traffic except through the overtaking effect of buses, and parking/loading considerations are not significant, it may be worthwhile to adopt a 24 hour operating period: This would be easier to enforce (less signing also being likely to be required) and would offer buses additional benefits on the occasions when congestion occurs during off-peak periods. In practice however, it may be difficult to justify restrictions which normally serve no useful purpose (e.g. even in London, where off-peak congestion is greater than in most cities, only 8% of with-flow bus lanes operate during off-peak periods).

It was noted at a number of sites that many drivers of non-priority vehicles avoided using a bus lane outside of its operational period. This may have been due to a variety of factors such as the deterrent effect of the road markings, unclear road signs or adverse conditions in the bus lane (e.g. parked vehicles).

6.5.2.2 Permitted Users

Permitted users of the with-flow bus lanes surveyed (as signed) included buses and pedal cyclists (all lanes), taxis (7 out of 22 lanes) and coaches (2 out of 22 lanes). Of the three contra-flow bus lanes studied, only buses were permitted at site 25, while pedal cyclists were also permitted at sites 15 and 24. Additional vehicle classes (not signed) were also permitted to use the bus lanes, as stated in the Traffic Regulation Order for each bus lane (e.g. emergency service vehicles, vehicles for disabled drivers, etc.) and there were also variations in the types of bus service permitted (e.g. stage carriage only, or to include works buses, school buses, express services, etc.). Details for each site are given in Appendix A.

The proportion of buses in the overall traffic stream at the sites surveyed varied between 1% and 13%, the average for all sites being 3.3%. Equivalent figures for pedal cyclists were 0%, 2% and 4.4% respectively. Where taxis were permitted, their volumes never exceeded 1% of total traffic. These figures indicate a low usage of bus lanes and it may be worthwhile in some circumstances extending their use to other vehicles which have a higher than average resource cost. Such vehicles may include multi-occupancy vehicles (such as car pools) and commercial vehicles.

The option to allow left turning vehicles to use a bus lane could also be considered where a short setback is provided, as at internal links within bus lane systems. (In fact, left turners were observed to violate the downstream end of the bus lane at a number of sites (e.g. site nos. 6, 12 and 18). This could decrease delay both for left turning vehicles and through traffic - which would normally share road space with each other - without significantly disbenefiting buses.

However, there may be difficulties with such extensions to categories of permitted users in terms of signing and enforcement (at least initially).

Suspicion as to the overall benefit of bus lanes must be heightened for drivers of non-priority vehicles by having to experience longer queues and seeing very few buses using the bus lane. Although increased queue length may be mistakenly perceived to be causing increased delay, low bus lane usage is indisputable, and bus lanes are likely to become more widely acceptable if more use is seen to be made of them, provided a fair discrimination is maintained.

6.5.3 Layout/Design Features

The uniformity in layout/design and signing between sites suggests that the guidance set out in H6/76 has been followed at the sites studied, with the exception of setback distances at some of the with-flow bus lanes which, because of their shortness, may have been causing additional delay to non-priority traffic (see Section 6.3). This apart, the bus lanes appeared to be generally operating satisfactorily and safely, although this latter point has not been statistically confirmed here. Some comments on individual aspects are given below.

Bus Lane Lengths

A summary of bus lane lengths in relation to link lengths for the sites studied is given in Table 5.2. In general, the bus lanes were provided over the majority of the link length, to offer buses greatest advantage, although shorter bus lanes were provided at some sites where shorter queues occurred. Many of the bus lanes could not physically be lengthened and of those that could none appeared to warrant lengthening. Although observed maximum queue lengths were shorter than the bus lane length at many sites, this rarely caused any obvious disbenefit to non-priority traffic and shortening such bus lanes now would be unlikely to be worthwhile.

Lane Widths

Bus lane widths at the sites studied varied between 2.9m and 3.6m, most being in the range 3.0 to 3.2m. This is in accordance with advice in H6/76. These lane widths were observed to be adequate, although the presence of pedal cyclists in the bus lane corresponding with a queue of traffic in the adjacent lane caused reductions in bus running speeds in some cases (see Section 6.5.1.4). It is unlikely that this could be avoided without a significant increase in bus lane width (e.g. perhaps of around 1m). Buses were also occasionally delayed where the lane adjacent to the bus lane was narrow and a vehicle (usually a commercial vehicle) encroached into the bus lane (e.g. at site 17, where the non-priority lane was as narrow as 2.6 metres in places).

Road Markings

Road markings were observed to be in accordance with the guidelines in H6/76 and there was no evidence to suggest that any modifications would be worthwhile. The possibility that lane markings are clearer than the accompanying road signs is suggested by the observation at some sites that some drivers avoided using peak hour bus lanes in off-peak periods. This is unlikely to cause significant disbenefits however.

The tapered length marking the start of a with-flow bus lane was provided at all sites usually being around 30m in length in accordance with guidelines in H6/76. Although some delay was experienced by traffic at this location, it is not likely that this would be noticeably reduced by a more generous taper.

None of the bus lanes studied were distinguished by a different surface texture/colour than that for adjacent non-priority lane(s).

Signing

Signs associated with the with-flow bus lanes for traffic approaching, using and leaving the bus lane link and for traffic joining it from side roads were found to be in accordance with advice given in H6/76. The observed variants to the options illustrated in Figure 4A of H6/76 were:

(i) Where taxis were permitted to use the bus lane, the word 'taxi' was inserted between the drawings of the bus and the pedal cycle in sign 812.1 and to the right of the pedal cycle in sign 654.

(ii) Where coaches were permitted - only at the two sites in Bristol (sites 8 and 9) - the words '& coaches' were displayed on the drawings of the bus in signs 812.1 and 654.

Time plates were always attached immediately beneath the main sign.

Similarly, the signs associated with the contra-flow bus lanes were also in accordance with advice contained in H6/76, Appendix I and illustrated in Figure 5A. The only variant noted was the sign denoting the start of the bus lanes at sites 15 and 24, where pedal cyclists were permitted to use the bus lanes as well as buses. The usual 'no entry except buses signs' (prohibitory sign numbers 616 and 619.3) were replaced by the mandatory signs showing buses and cyclists as the only vehicles permitted to enter the street. This sign is illustrated in the photograph of site 24 in the Data Base Appendix. Moving violations were only observed at site 24, a short (58m) contra-flow lane. These only totalled 3 vehs/hr and it is uncertain to what extent they were a result of the signing.

Moving violations were generally a low proportion of the total traffic at all of the bus lanes surveyed (see section 6.5.1.5). Very few violations of the start of a bus lane, which may be related to signing/ road markings rather than queue avoidance were noted (<1% of all traffic) and signing would therefore appear to be satisfactory.

The effectiveness of the signing of parking/loading restrictions which accompanied many of the bus lanes is difficult to assess. Such signing appeared clear and conspicuous and was consistent with similar signing adopted in situations unconnected with a bus lane. Levels of parking/loading violations were generally low except at two sites (see Section 6.5.1.5) where they would probably have occurred regardless of signing characteristics due to frontage activity. The prevention of parking/loading in these circumstances would probably have to be through the introduction of kerbside fencing, although this may unnecessarily restrict pedestrians' opportunities to cross the road.

TABLE 6.1 : MEASURED AVERAGE JOURNEY TIMES AND TRAFFIC FLOWS FOR PRIORITY AND NON-PRIORITY VEHICLES[1]

SITE NO.[2]	PEAK (P)/ OFF-PEAK (OP	SURVEY NO.	MEASURED AVERAGE JOURNEY TIME (SECS/VEH)			AVERAGE TRAFFIC FLOW (VEH/HR)		
			NON-PRIORITY VEHS	PRIORITY VEHS[3]	DIFFERENCE[4]	BUSES	PEDAL CYCLES[5]	OTHER TRAFFIC
1	P	1	27	16	11	21	10	850
1	P	2	28	23	5*	21	17	810
1	OP	1	22	17	5*	18	6	640
1	OP	2	18	14	5	15	7	610
2	P	1	42	25	17	31	9	750
2	P	2	44	30	14	32	1	790
2	OP	1	32	28	4*	28	6	530
2	OP	2	30	32	-2*	28	3	510
3	P	1	31	41	-10*	22	76	670
3	P	2	37	39	-2*	21	88	750
3	P	3	40	35	5	23	89	900
3	P	4	31	30	1*	20	76	740
3	P	5	36	33	3*	20	71	830
4	P	1	155	61	94	37	81	1860
4	P	2	103	68	35	37	68	1890
4	OP	1	66	58	8*	48	53	1400
4	OP	2	78	55	23	46	52	1650
5	P	1	69	51	18	9	3	760
5	P	2	74	35	39	13	15	780
5	OP	1	34	40	-6	6	27	580
5	OP	2	36	33	3	8	8	650
6	P	1	174	89	85	21	219	630
6	P	2	140	73	67	21	153	730
6	OP	1	70	54	16*	25	111	870
6	OP	2	70	70	0*	23	79	800
7	P	1	242	145	97	19	164	1010
7	P	2	255	203	52	17	152	990
7	OP	1	124	98	26	14	49	800
7	OP	2	129	114	15*	14	53	770
8	P	1	66	41	25	33	155	1040
8	P	2	60	35	25	29	155e	1030
9	P	1	143	66	77	32	151	750
9	P	2	113	51	62	33	137	740
10	P	1	65	41	24	61	N/A	1630
10	P	2	66	40	26	64	N/A	1610
10	OP	1	55	43	12	49	N/A	1110
10	OP	2	53	48	5	49	N/A	1020
11	P	1	47	42	5*	43	82	1480
11	P	2	48	51	17*	43	101	1500
12	P	1	73	52	21	80	66	1960
12	P	2	80	60	20	77	53	1790
12	OP	1	39	50	-11*	53	10	1250
12	OP	2	36	47	-11*	57	30	1160

TABLE 6.1 : (Continued)

SITE NO.[2]	PEAK (P)/ OFF-PEAK (OP)	SURVEY NO.	MEASURED AVERAGE JOURNEY TIME (SECS/VEH)			AVERAGE TRAFFIC FLOW (VEH/HR)		
			NON-PRIORITY VEHS	PRIORITY VEHS[3]	DIFFERENCE[4]	BUSES	PEDAL CYCLES[5]	OTHER TRAFFIC
13	P	1	55	55	0*	36	39	1210
13	P	2	52	48	4*	39	55	1280
14	P	1	102	72	30	16	45	820
14	P	2	99	65	34	15	40	780
15∇	P	1	63	47	16	11	21	570
15∇	P	2	60	45	15	11	9	590
15∇	OP	1	47	62	-15*	10	0	240
15∇	OP	2	42	60	-18*	8e	0e	360e
16	P	1	182	93	89	25	21	930
16	P	2	162	94	68	27	18	960
17	P	1	127	97	30*	23	8	1450
17	P	2	109	98	11*	22	15	1260
18	P	1	78	55	23	61	N/A	2830
18	P	2	75	56	19	N/A	N/A	N/A
19	P	1	36	45	-9*	33	13	700
19	P	2	39	50	-11*	35	19	730
20	P	1	82	55	27	22	10	1180
20	P	2	75	60	15*	N/A	N/A	N/A
21	P	1	27	44	-17*	101	29	650
21	P	2	31	35	-4*	N/A	N/A	N/A
22	P	1	49	48	1*	64	N/A	1140
22	P	2	46	40	6*	N/A	N/A	N/A
23	P	1	22	26	-4*	95	54	630
23	P	2	22	27	-5*	98	49	560
24∇	P	1	101	23	78	12	11	90
24∇	P	2	82	36	46	12	11	70
24∇	OP	1	103	42	61	13	11	100
25∇	P	1	338	142	196	35	N/A	900e
25∇	P	2	251	137	113	30	N/A	500e
25∇	OP	1	217	164	53	26	N/A	900e
25∇	OP	2	187	136	51	23	N/A	500e

1 These are differences for the 'with' bus lane situation
2 Sites marked ∇ are contra-flow bus lanes
3 These journey times exclude time spent at bus stops and associated acceleration/ deceleration effects
4 Different = journey time for non-priority vehicles minus journey time for priority vehicles. Those differences marked with an asterisk are not statistically significant (5% level).
5 e = estimated

TABLE 6.2 : SETBACK DISTANCES AT SIGNAL CONTROLLED JUNCTIONS AND THEIR EFFECTS ON PREDICTED MAXIMUM CAPACITY

SITE*	SETBACK (M) L	EFFECTIVE GREEN TIME G (SECS)	OPTIMUM** SETBACK (M)		PREDICTED MAXIMUM SATURATION FLOWS (PCU/HR)		REDUCTION IN CAPACITY (%)
			1	2	WITHOUT BUS LANE (S_w)	WITH BUS LANE*** (S_b)	
1∇	42	50	100	138	3610	2350	35
2+	18	N/A	N/A	N/A	2788	2424	13
3	50	42	84	100	3120	2460	21
4+	28	N/A	N/A	N/A	2727	2485	9
5+	54	N/A	N/A	N/A	1825	1825	0
6	37	45	90	136	3954	2384	40
8	56	37	74	112	3959	2880	27
9+	30	N/A	N/A	N/A	2101	1820	13
12∇	31	40	80	123	6070	4218	31
13∇	64	56	112	166	5842	4461	24
14+	31	N/A	N/A	N/A	1808	1616	11
16	124	33	66	100	3970	3970	0
18	37	87	174	249	5625	3903	31
19∇	74	52	104	151	3796	2798	26
20	60	17	34	52	6025	6025	0
22	75	82	164	261	4170	2479	41
23	10	45	90	134	3873	1958	49

* Sites marked ∇ contain left turn only lane in the setback
Sites marked + are roundabout entries

** 1. Optimum setback (m) = 2g (H6/76)
2. Optimum setback (m) = $5.5S_w\ g/3600n$
where n = no. of lanes @ stop line
g = effective green time (secs)

Theoretical optimum setbacks are not known/given for the roundabout entries

*** $$S_b = \frac{S_w t_1 + 1800\,(n-1)t_2}{g} \text{ pcu/hr}$$

where $$t_1 = \frac{3600_n L}{5.5S_w}$$

L = length of setback (m)

$t_2 = g - t_1$

See Section 7.1.1 for explanation.

Note : For signal controlled entries these formulae apply only to non-flared entries.
: See Section 6.3 for explanation of roundabout entry saturation flows.

TABLE 6.3 : AVERAGE PACKING FACTORS AT THE SURVEY SITES

SITE NO.*	SETBACK LENGTH, L	PACKING FACTOR**	SATURATION FLOWS (pcu/hr)***		
			1	2	3
2+	18	0.3	2424	2202	1375
4+	28	0.2	2485	2168	2130
5	54	0.9	1825	1825	1297
6∇	37	0.3	2384	1972	1750
8∇	56	0.2	2880	2016	2200
9∇	30	0.2	1820	1448	nc
14+	31	0.7	1616	1542	1455
16	124	1.0	3970	3970	3760
18	37	0.3	3903	3688	nc
20	60	0.6	6025	5269	5300
23	10	0.0	1958	1800	nc

* Sites marked ∇ had exit blocking problems which could have restricted nearside lane usage. Sites marked + had high proportions of right turning traffic which could have restricted nearside lane usage.

** This is the ratio of the actual queue in the nearside lane in the setback to the maximum queue, under saturated conditions.

*** 1 : Predicted maximum saturation flow, excluding packing factor effects.
2 : Predicted maximum saturation flow, including packing factor effects.
3 : Average 'calibrated' saturation flow using CONTRAM (see Section 8.4.1.1).

nc : not calibrated

TABLE 6.4 : DEGREE OF ILLEGAL STOPPING/PARKING IN BUS LANE*

SITE NO.	PEAK/ OFF-PEAK	% OF SURVEY AFFECTED BY 1 OR MORE VEHS.	SITE NO.	PEAK/ OFF-PEAK	% OF SURVEY AFFECTED BY 1 OR MORE VEHS.
1	P	1.2	11	P	100.0
1	P	0.4	11	P	11.1
1	O	0.6	12	P	0.0
1	O	0.0	12	P	0.0
2	P	4.1	12	O	4.6
2	P	0.0	12	O	24.9
2	O	0.0	13	P	16.3
2	O	2.0	13	P	1.7
3	P	0.1	14	P	60.6
3	P	3.1	14	P	43.3
3	P	0.6	15	P	59.0
3	P	0.0	15	P	21.1
3	P	0.0	15	O	100.0
4	P	0.0	15	O	100.0
4	P	16.7	16	P	0.0
4	O	8.1	16	P	0.0
4	O	0.0	17	P	13.9
5	P	34.4	17	P	8.7
5	P	0.0	18	P	0.0
5	O	0.0	18	P	0.0
5	O	0.0	19	P	6.6
6	P	28.1	19	P	22.3
6	P	49.0	20	P	0.0
6	O	100.0	20	P	0.0
6	O	100.0	21	P	0.0
7	P	0.0	21	P	c.30.0
7	P	68.3	22	P	0.0
7	O	3.4	22	P	0.0
7	O	100.0	23	P	0.0
8	P	41.4	23	P	c.16.0
8	P	8.1	24	P	0.0
9	P	47.4	24	P	0.0
9	P	30.9	24	O	0.0
10	P	6.0	25	P	18.7
10	P	4.2	25	P	0.0
10	O	5.0	25	O	2.9
10	O	99.3	25	O	0.0

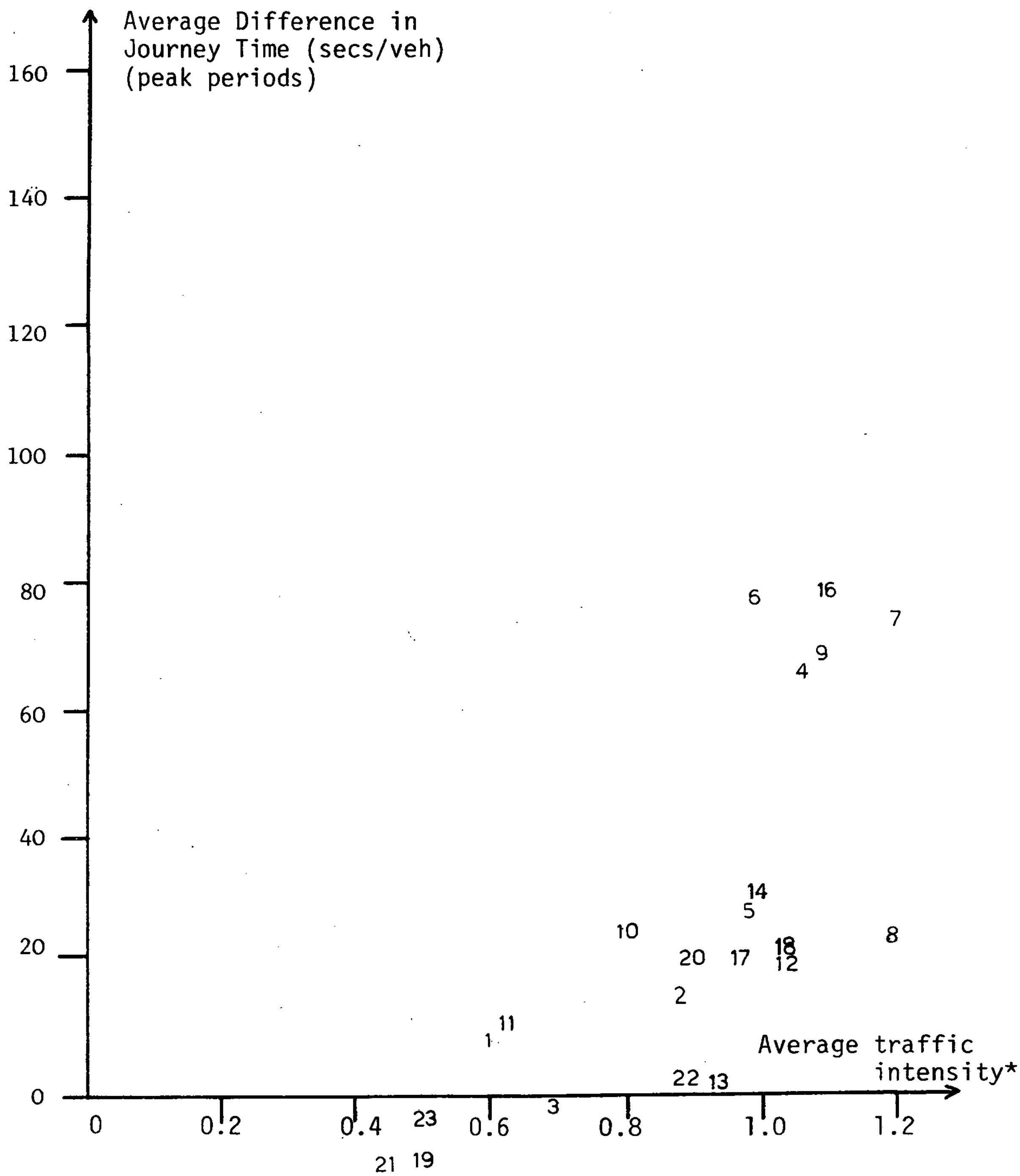
* Some of these events may not have been illegal under the terms of the Traffic Order (e.g. furniture removals), but are included as having a possible detrimental effect on the operation of the bus lane.

TABLE 6.5 : PERCENTAGE OF MOVING NON-PRIORITY VEHICLES VIOLATING THE BUS LANE

SITE NO.	PEAK/ OFF-PEAK	% VIOLATORS*	SITE NO.	PEAK/ OFF-PEAK	% VIOLATORS*
1	P	2.9	11	P	0.0
1	P	2.1	11	P	0.0
1	O	1.1	12	P	1.3
1	O	1.8	12	P	1.9
2	P	0.8	12	O	0.2
2	P	1.3	12	O	0.2
2	O	0.4	13	P	0.1
2	O	0.4	13	P	0.1
3	P	3.1	14	P	4.9
3	P	1.9	14	P	8.2
3	P	3.6	15	P	0.1
3	P	5.0	15	P	0.0
3	P	5.6	15	O	0.0
4	P	1.3	15	O	0.0
4	P	0.5	16	P	2.4
4	O	0.1	16	P	2.8
4	O	0.1	17	P	2.3
5	P	0.7	17	P	3.1
5	P	0.1	18	P	0.4
5	O	0.1	18	P	0.1
5	O	0.2	19	P	0.0
6	P	17.2	19	P	0.0
6	P	10.2	20	P	0.2
6	O	5.9	20	P	0.2
6	O	3.8	21	P	0.4
7	P	1.7	21	P	0.4
7	P	1.2	22	P	1.7
7	O	1.0	22	P	2.1
7	O	0.1	23	P	0.1
8	P	7.4	23	P	0.0
8	P	6.1	24	P	1.5
9	P	2.4	24	P	2.9
9	P	3.6	24	O	8.0
10	P	0.0	25	P	0.0
10	P	0.0	25	P	0.0
10	O	0.0	25	O	0.0
10	O	0.0	25	O	0.0

* Violators are taken as those non-priority vehicles violating at least the downstream half of the bus lane

FIGURE 6.1 : RELATIONSHIP BETWEEN MEASURED AVERAGE DIFFERENCE IN JOURNEY TIME BETWEEN PRIORITY AND NON-PRIORITY VEHICLES AND AVERAGE TRAFFIC INTENSITY



Note: Numbers refer to site numbers (see Table 5.1)

FIGURE 6.2. RELATIONSHIP BETWEEN MAXIMUM JOURNEY TIME SAVINGS FOR PRIORITY VEHICLES AND BUS LANE LENGTH FOR DIFFERENT JUNCTION CAPACITIES (U)

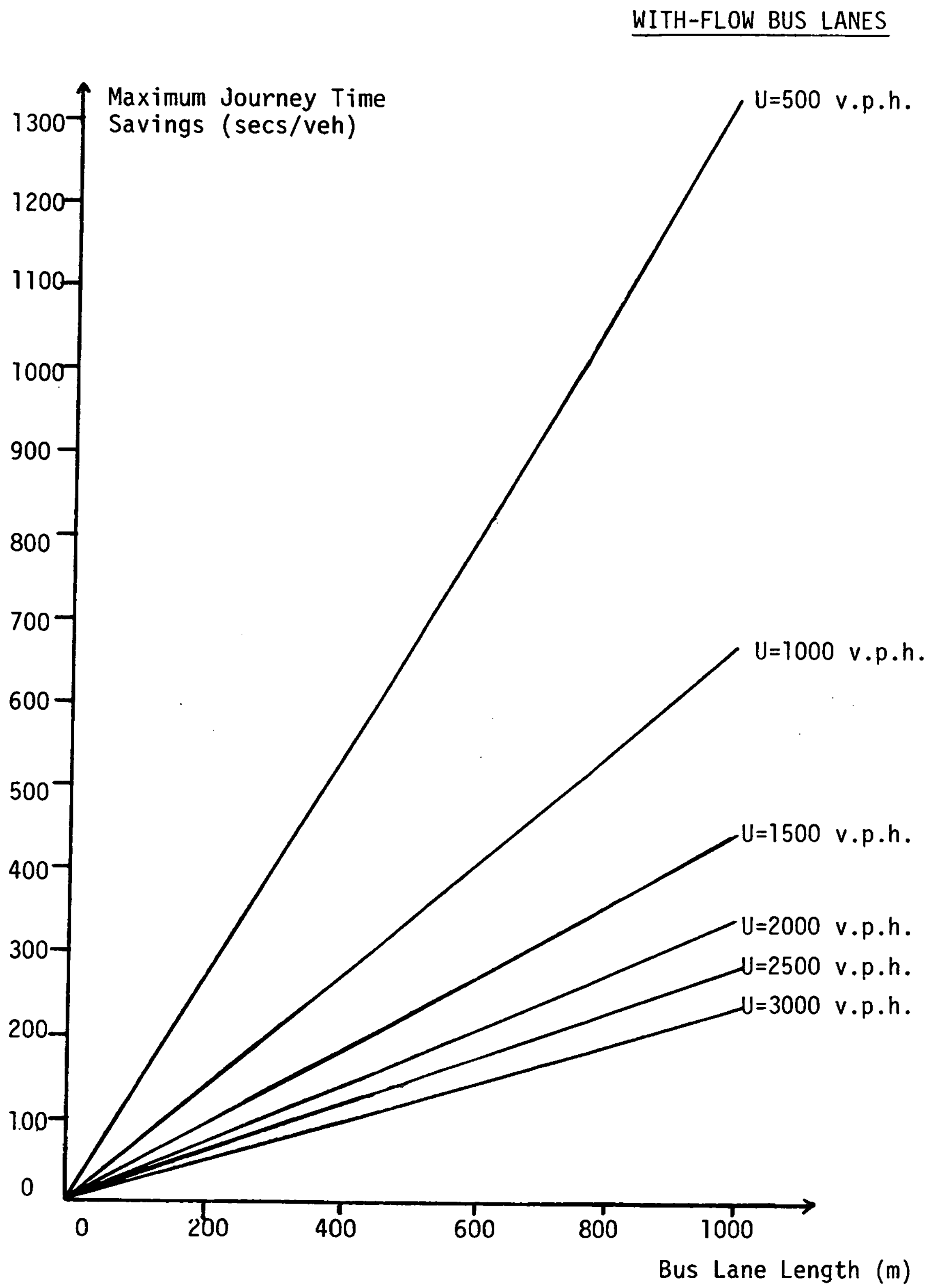


FIGURE 6.3 : RELATIONSHIP BETWEEN MEASURED BUS SPEEDS AND PEDAL CYCLE FLOWS AT ONE SITE (SITE9).

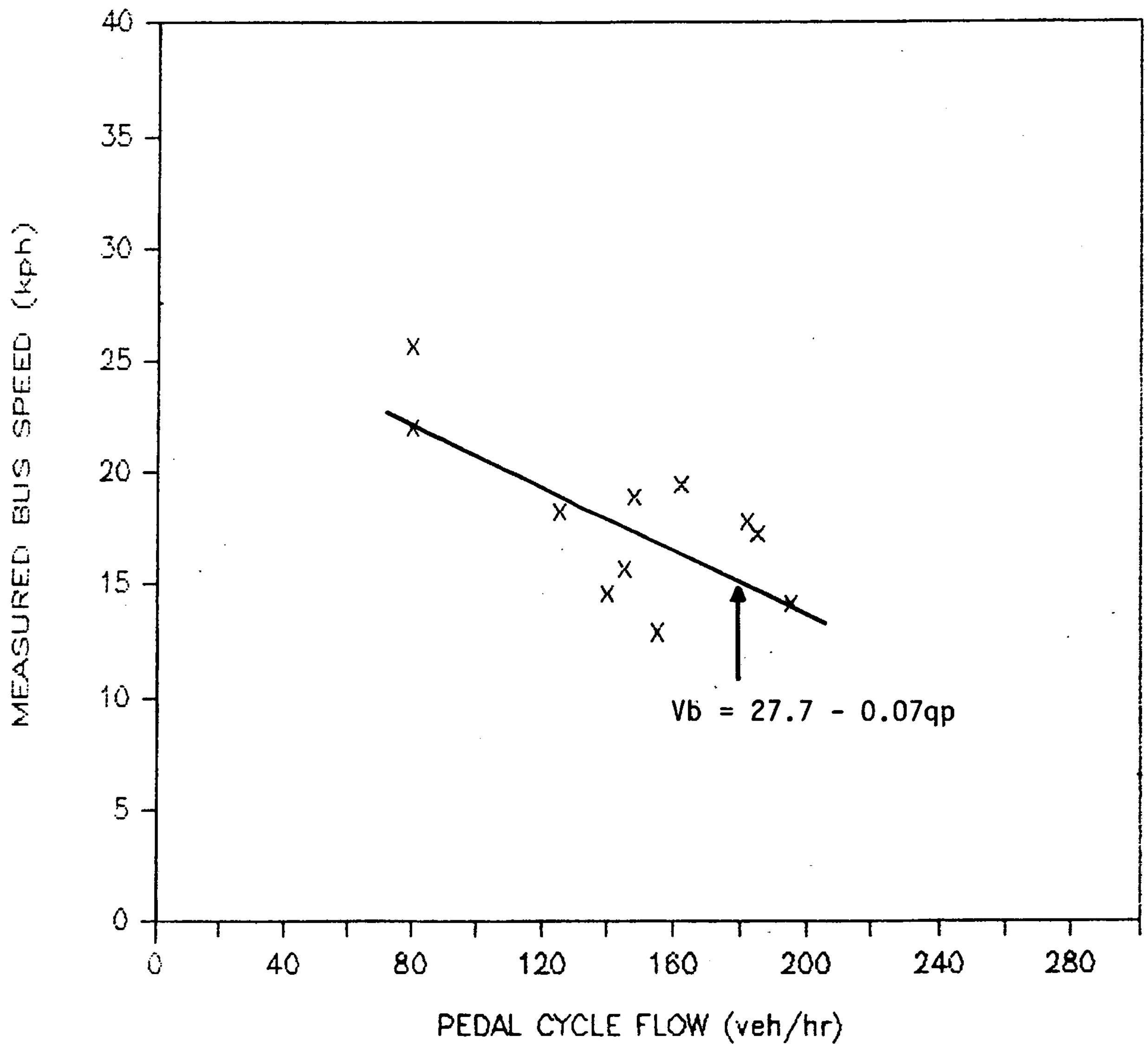
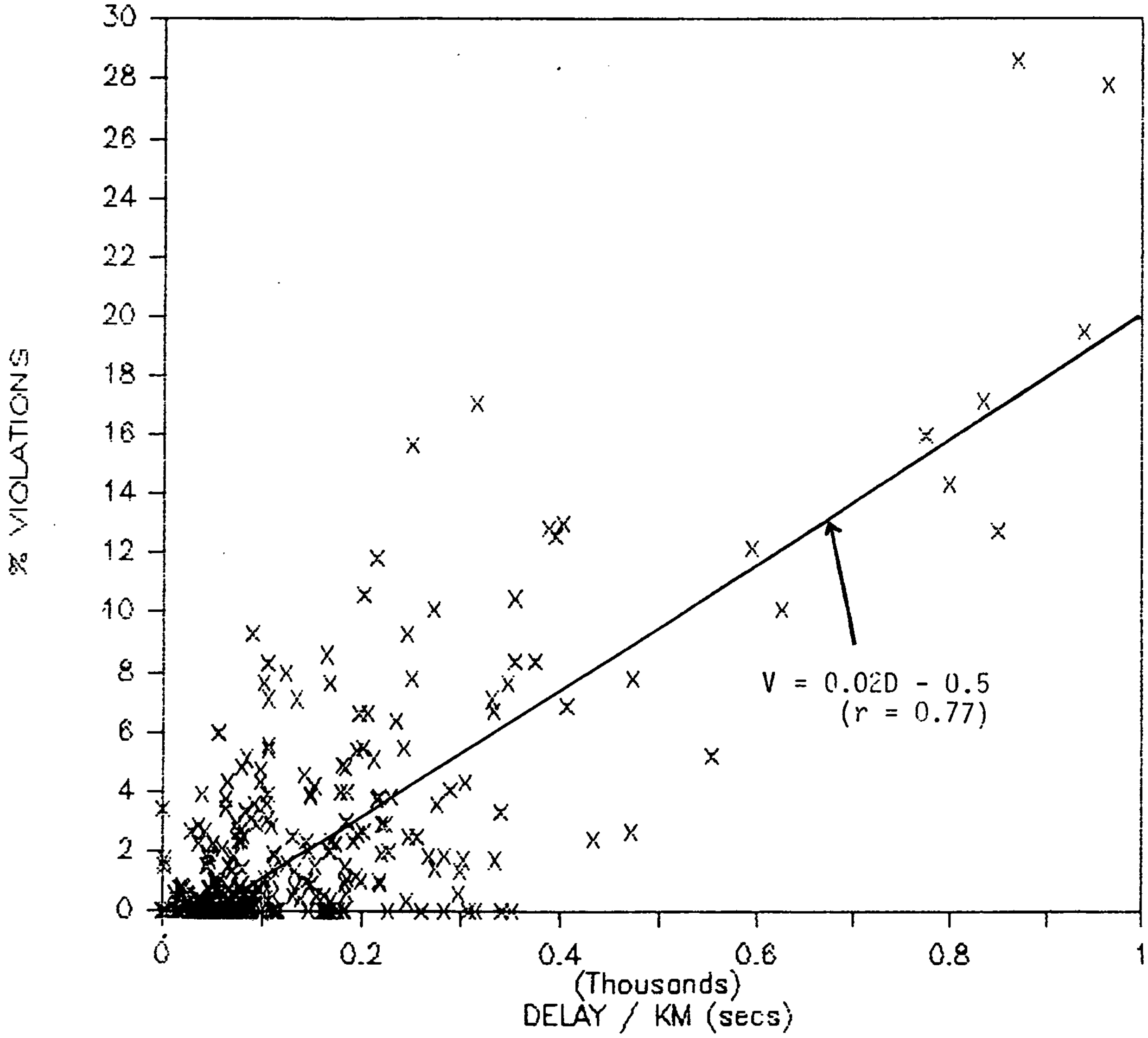


FIGURE 6.4: RELATIONSHIP BETWEEN THE PERCENTAGE OF BUS LANE VIOLATIONS (MOVING) AND DELAY PER KILOMETRE OF BUS LANE.



SECTION SEVEN

COMPUTER MODELLING: ANALYSIS

The evaluation of the with-flow and contra-flow bus lanes assessed in this study required estimates to be made of traffic performance without the bus lane to compare with measurements taken for the 'with' bus lane situation. Two methods of approach were considered for this evaluation:-

(i) 'Step-by-step' methods involving judgements and estimations on the effects of each factor individually (possibly including some limited modelling of certain parameters).
(ii) The use of computer-based traffic models.

It was considered that the latter approach would be preferable if a readily available model could adequately reflect the various effects of a bus lane. A consistency of approach for evaluation could then be achieved, and it would also allow easier assessments to be made of the sensitivity of key parameters such as queue length and delay to changes in their controlling variables, to allow 'optimum' designs to be achieved. This may be difficult in a step-by-step approach, where subjective judgements at different levels could vary both within and between sites.

The evaluation and application of computer-based traffic models has therefore formed a major part of this study. Within the study timetable, it has not been possible to explore fully other methods of approach, although it was known that alternative approaches to modelling were being developed in detail by Colin Buchanan and Partners in their concurrent study of bus priorities in London. These methods are thought to be similar to that described in Section 6, which assumes that the bus lane has no adverse effect on non-priority vehicles other than through the overtaking effect of buses, and therefore produces a maximum likely benefit of the bus lane.

Following the review of the likely impacts of the introduction of a bus lane (Section 3) and the performance characteristics (Section 4), the main requirements of a computer model to evaluate the quantitative effects of a bus lane were recognised as being the ability to model:

(i) Changes in available road space for priority and non-priority vehicles (to enable queue lengths, possible blocking and associated factors to be determined)

(ii) The journey times/delays/queue lengths for priority and non-priority vehicles separately (for the bus-lane situation) to reflect the changes that are likely to occur on the introduction of the bus lane

(iii) The different forms of junction control/layout

(iv) The effects of 'blocking back' both from downstream links and into upstream links on vehicles using the bus lane link, those joining it from side roads and cross traffic

(v) The likelihood and/or effects of vehicle diversions

(vi) The effects of different parking/loading restrictions, associated levels of abuse and bus-lane violations by moving vehicles

(vii) Vehicle operating costs

Two computer models supported by the Department of Transport were identified as being suitable for evaluation, TRAFFICQ and CONTRAM. TRAFFICQ had already been used by the Consultants, Jamieson Mackay and Partners in the preliminary study[8] of the Evaluation of Bus Lanes, while CONTRAM had not previously been assessed in this context. These programs are described in Sections 7.1 and 7.2. In addition, BLAMP, a program developed by West Yorkshire Metropolitan County Council specifically for modelling bus lanes, was kindly made available during the course of this study, and was also evaluated at a sample of sites. BLAMP is described in Section 7.3.

7.1 TRAFFICQ : DESCRIPTION AND SENSITIVITY TESTS

TRAFFICQ was developed to investigate the likely effects of introducing new traffic schemes in 'small' complex urban networks where traffic congestion is prevalent. It can model networks containing up to some 60 directional road links where vehicle routes are known or can be predicted with reasonable accuracy. It is not a traffic assignment model (unlike CONTRAM), vehicle routes having to be specified between each origin and destination. TRAFFICQ is a simulation model which works by simulating what happens to individual vehicles as they enter, pass through and leave a road network. Many of the calculations within TRAFFICQ are stochastic in nature (i.e. they contain a degree of randomness) and are intended therefore to reflect conditions more realistically than models based on average equations. For example, TRAFFICQ should be able to model the effects of temporary blocking back of one junction into another in a way that methods based on average queue lengths cannot.

The principal inputs into TRAFFICQ are network layout details, vehicle routes, junction information (type, saturation flows, etc.) vehicle free running speeds and origin-destination traffic flows. Pedestrian information can also be included if necessary. The principal outputs are frequency distributions of queue lengths and journey times on selected links, average link/network journey times, pedestrian delay distributions and fuel consumption estimates.

TRAFFICQ is supported by the Department of Transport and is available in both mainframe and micro-computer versions. It has become widely used for assessing the effects of traffic management schemes in small to medium sized networks.

7.1.1 **With-Flow Bus Lanes**

The application of TRAFFICQ to links containing with-flow bus lanes was initially considered using a network layout of the sort illustrated in Figure 7.1. In this example, a section of road containing a bus lane is represented within TRAFFICQ as a number of separate links, each describing the different geometric and operational aspects of the link. These links include the approach to the bus lane section itself (for which priority and illegal users are assigned to different links than non-priority vehicles) and the set-back section which is shared by all traffic. Different vehicle classes are fed onto the links using separate 'dummy' origins, which enables different routes and flows to be specified for each class as necessary.

SENSITIVITY TESTS

Before adopting this method of network representation for general evaluation a series of sensitivity tests were undertaken based on data from our regular survey site at Shirley Road, Southampton (Site 03). These were considered necessary to ensure that TRAFFICQ was modelling conditions as expected and to ascertain which input parameters were most sensitive and would therefore need most careful consideration. The key parameters which were varied individually within the sensitivity tests were saturation flows, demand flows, free running speeds, and certain geometric characteristics, such as setback length. The results from these sensitivity tests, in terms of the effect on journey times/queue lengths were generally as expected, although the trends were not always as 'smooth' as might have been anticipated. However, it is also important to ensure that equivalent modelling of the 'without bus lane' situation also produces realistic results, both in absolute terms and in comparison with the 'with bus lane' situation

The 'without' bus lane network is also illustrated in Figure 7.1 and can be seen to differ from the 'with' bus lane network in that the separate 'links' for priority and non-priority vehicles have been combined. 'Artificial' queueing points were maintained in these tests for the 'without' bus lane network (i.e. where the bus lane would start and end) to maintain link compatibility between networks. Further sensitivity tests showed that the removal of these queueing points always led to lower overall journey times, because the occasional constraints of these queueing points (even with high saturation flows) were removed. The most appropriate 'without' bus lane option (i.e. the one which truly reflected the effect of the bus lane rather than characteristics of the model) was unclear, however, and led to some dissatisfaction with the layout as envisaged in Figure 7.1. Again, sensitivity tests on this network varying the parameters described above gave generally satisfactory results when viewed independently from the 'with' bus lane network. It should be noted here that cruise speeds in these and in all later analyses were assumed to be the same for all vehicle classes both in the 'with' and 'without' bus lane situations. Also, TRAFFICQ does not model speed/flow effects per se (e.g. the effect of concentrating two lanes of non-priority traffic into one) relying on user inputs.

A further set of analyses was then undertaken varying the simulation increment in the model (i.e. the rate at which TRAFFICQ takes observations of each vehicle). This produced unstable results, as summarised in Table 7.1. Predicted journey times for priority and non-priority vehicles for the 'with' bus lane situation increased regularly as the simulation increment was increased, ranging from 43 to 70 seconds for an increment range of 3 to 6 seconds. A large simulation increment may be expected to give less accurate results in absolute terms, but should not normally lead to a systematic trend as observed. In the 'without' bus lane case, predicted journey times varied for different simulation increments but not in the same manner as in the 'with' bus lane case. The predicted disadvantage to non-priority vehicles from the presence of the bus lane therefore varied between 0 and 23 seconds per vehicle depending on the simulation increment chosen. Similar variations were observed when the merge point at the end of the bus lane was modelled in different ways (e.g. as a major/minor junction or as a true merge situation) although it is thought that the best representation is the use of a 'dummy' signal controlled junction where the queueing points 9, 10 and 11 are allocated 100% green time.

One reason for the instability is thought to be in the modelling of short links where cruise times are of a similar order of magnitude as the simulation increment, thus creating boundary problems in the calculations. This occurs when the setback is modelled as a separate link by introducing an artificial queueing point at the end of the bus lane. (The problem is likely to be exacerbated at roundabout entries where much shorter setbacks are usually employed than at signals due to the different departure characteristics of vehicles). This could be overcome to some extent by using a small simulation increment and increasing the cruise times, but it is unlikely that a consistent approach leading to accurate and consistent results could be formulated to cover all situations. With actual differences in journey time for non-priority vehicles likely to be small in many cases, it is important that these differences are accurately reflected and are not a function of the characteristics of the model being used. For these reasons, the modelling of bus lane links using TRAFFICQ as described above was discontinued.

An alternative and somewhat similar representation within TRAFFICQ of a link containing a with-flow bus lane is to take advantage of the link sectioning procedure in which links are divided into three sections, each having its own number of lanes. An example illustration of this layout is given in Figure 7.2, where the bus lane is shown as reducing the width of Section 2 of the link (the bus lane section) by one lane. However, this layout does not allow the effect of the bus lane on priority vehicles to be obtained directly, this saving having to be determined externally from a consideration of queue lengths for non-priority vehicles predicted by the model. The 'without' bus lane situation is modelled simply by increasing the width of Section 2 by one lane. Problems associated with 'artificial' queueing points and short links as described above do not arise with this layout. A minor drawback may be that merging delay at the start of the bus lane is not modelled by TRAFFICQ, which assumes perfect merging, but this effect has been found to be small.

The sensitivity of journey time for non-priority vehicles to changes in the simulation increment, using the layout illustrated in Figure 7.2 is shown in Table 7.1 (the data is consistent with that used on the network shown in Figure 7.1). The results in Table 7.1 for this simple network are relatively consistent for both the 'with' and 'without' bus lane situations, the disbenefit of the bus lane to non-priority vehicles on this occasion only varying between 1 and 3 seconds per vehicle for the different simulation increments. Furthermore, the absolute values of predicted average journey time for non-priority vehicles were closer to those observed (32 secs/veh). These results were considered satisfactory and modelling in this manner was therefore continued.

SATURATION FLOWS

A key aspect of the modelling was considered to be the way in which TRAFFICQ could be used to reflect the effect of short setbacks which may restrict the capacity of the junction at the end of the link and so increase delays to non-priority vehicles. A typical stopline saturation flow profile for this condition is illustrated in Figure 7.3, which depicts an instantaneous reduction in saturation flow of around 50% when the vehicles in the setback storage area have cleared. In practice, the extent of the reduction is related to the ratio of the saturation flows adjacent to the end of the bus lane and at the stopline, the vehicle usage of the nearside lane in the setback (the 'packing' effect) and vehicle move-up characteristics. The profile in Figure 7.3 assumes that vehicles emerging into the setback area do not reduce their headways (e.g. by lane changing) such that the saturation flow is greater at the stop line than at the end of the lane adjacent to the bus lane. Some degree of 'move-up' may well occur in practice, and the situation depicted in Figure 7.3 is therefore likely to represent the maximum loss of capacity due to a short setback.

The profile is also a simplification in that it does not allow for any vehicles which arrive from the bus lane (priority vehicles or violators) when the setback is discharging. (Those arriving when it is filling are irrelevant as they merely take the place of non-priority vehicles.) Observations showed that, on average, only 1 or 2 pcu's arrived during this period and these could be reasonably ignored as the setback was rarely completely filled (as assumed) due to the abrupt ending of the bus lane. Furthermore, the queueing space of 5.5m per vehicle used in these analyses, as measured in Southampton[19] and recommended in TRAFFICQ[9], is applicable to densely packed vehicle streams containing principally cars and increasingly underestimates capacity loss as the proportion of commercial and public service vehicles increases.

However, where flows of priority vehicles and/or violators are particularly high, an adjustment to the profile depicted in Figure 7.3 may be necessary (i.e. a recalculation of t).

However, it should be emphasised that the accuracy of the saturation flow estimate for the 'with' bus lane situation depends largely on the accuracy with which the location of 't' (Figure 7.3) is able to be estimated. This requires consideration of the various effects of the likely packing factors (see Section 6.4), likely moving violations (Section 6.5.1.5) and the flow of buses. Estimates of these effects are best based on observations from similar local bus lanes, although results from the sections listed above could be helpful. An adjustment to the profile depicted in Figure 7.3 may therefore be necessary in a variety of circumstances. (An example of this significant effect is illustrated in Appendix F, Section 11.2.1.)

The modelling of this situation by TRAFFICQ was assessed using a 'network' of the type illustrated in Figure 7.2. Although the 10m setback length chosen is particularly short, it has been observed where the nearside lane of the setback is restricted to left turn only vehicles and an extreme example was best for these sensitivity tests. For these trials, a stopline saturation flow of 3600 pcu/hr was used together with effective green and cycle times of 50 and 100 secs respectively. Arrival flows were then systematically increased and predicted average journey times monitored.

Results are shown in Figure 7.4. The setback of only 10m would, in practice, restrict the practical capacity of the entry to around 1000 vehs/hr. However, it can be seen from Figure 7.4 that this is not reflected by TRAFFICQ which predicts sharply increasing journey times only after an arrival flow of over 1500 vehicles per hour. Thus, when a short setback exists, a saturation flow should be input *which reflects the loss of capacity this causes.* This requirement is not wholly satisfactory however, as (for example) the 'true' saturation flow will be underestimated to some extent on all occasions when both the setback is too short and the approach is undersaturated. Nevertheless, modelling was continued in this way, as the situation of most interest was where long queues formed adjacent to the bus lane and the junction was clearly oversaturated.

It was expected that results from TRAFFICQ would be sensitive to the random number seed used, but sensitivity tests showed that, at this site, which operated generally under undersaturated conditions, results were relatively stable. (More instability was subsequently found at the 'before and after' site in London, which operated under oversaturated conditions for significant lengths of time. This is illustrated in Appendix F.)

ROUNDABOUTS

The modelling of roundabouts by TRAFFICQ required a knowledge of both the circulating flow on the roundabout, which was measured in the surveys, and the key geometric factors controlling entry capacity as set out in LR942[23]. These geometric factors include measurements of entry width, approach width and the length of flare on the approach arm. One method of analysing the effect on the entry capacity for non-priority vehicles of the introduction of a bus lane was to consider the setback as a flare, which may itself be superimposed on an existing flare. Using this assumption together with predictive formulae given in LR942[23], the relationship between entry capacity and flared length, or in this case setback length, was investigated for different levels of circulating flow. Typical examples are given in Figure 7.5. In these examples, it is seen that the effect of setback length on entry capacity reduces as the setback length increases, as may be expected. Also, as the circulating flow is increased, entry capacity can be maintained with shorter flared lengths, again as expected. While these relationships were developed from entries with gradual rather than 'abrupt' flares that occur where a bus lane ends, similar effects would be expected. This approach is therefore one that has been adopted in these analyses. Further discussion of this and other possible methods of assessing the effects of a bus lane on roundabout entry is included in Section 8.

MODELLING

Where no setback is provided at a junction, entry capacity/saturation flow may be reduced considerably as an entry lane has been lost. In this situation in the modelling, 'with' bus lane saturation flows were simply reduced by the amount corresponding to the 'lost' lane.

The basic network layout used for modelling the 'with' and 'without' bus lane cases is as shown in Figure 7.2 except that a link was specified from the start of the bus lane to the downstream stop line, to enable predicted journey times over this distance to be compared directly with those measured. The effect of modelling a bus lane link within TRAFFICQ as two links instead of one was assessed by comparing the journey times predicted for the two layouts using a typical data set. It was found that higher overall journey times were always predicted when two links were modelled: Differences ranged from 7% (or 8 secs) to 15% (or 23 seconds) for traffic intensities ranging from 0.5 to 0.9. Similar results were obtained when the bus lane was removed. These results indicated that 'with' and 'without' bus lane comparisons have to be made using the same link configuration (i.e. if the start of the bus lane is modelled with a queueing point for the 'with' bus lane case, the 'without' bus lane network would also have to contain a queueing point at this location).

The layout shown in Figure 7.2 was enhanced at each survey site as necessary to include other features which needed to be modelled including pelican crossings, side roads and upstream junctions/approaches. Pelican crossings were modelled by first calculating the average cycle time for the pelican based on the number of times the pelican was 'called' during the survey period. This did not accurately represent reality as, for example, pelicans were sometimes more frequently called towards the end of a morning peak period. However, the effect of pelican crossings was generally found to be small (see section 8.5). The effective green time was taken to include the flashing amber period at most sites, although where pedestrian flows were high, a proportion of this period was included. The option to link the pelican to adjacent signal controlled junctions was not required at the study sites, each pelican being isolated. Pedestrian delays were not considered as, at pelican crossings, they should be unaffected by the presence of a bus lane.

BUS JOURNEY TIMES

Where bus lanes on consecutive links were surveyed, a single network layout was constructed for evaluation. An example of a layout covering most of these features is given in Figure 7.6. In this example layout, the effect of the bus lane on non-priority vehicles is obtained directly, but the estimated journey time for buses required further calculation. For links where a setback is provided (e.g. links 13 and 16 in the example) it was decided to calculate bus journey times from a consideration of queue lengths for non-priority vehicles and junction capacity. Average queue lengths are output by TRAFFICQ for 10 consecutive periods throughout the modelling, and occasions where the predicted queue length exceeds the 'effective' setback distance can be observed. (The 'effective' setback distance was taken as the actual distance multiplied by the average packing factor observed.) When this occurs the saving to buses can be estimated from the time a bus joining the end of this queue would have taken to reach the start of the effective setback. The formula used for this calculation was:

$$T_{sb} = (N_q - N_s)/C \qquad \text{........... 7.1}$$

where T_{sb} = time saved by buses (secs)

N_q = average number of pcus queueing on the link in the time period

N_s = average number of pcus which can fit into the effective storage area

C = entry capacity (pcus/sec)

$$C = \frac{\text{saturation flow x effective green time}}{\text{cycle time}}$$

Values of T_{sb} can be calculated for each time interval and averaged, weighting by the number of buses in each interval, if variable. The result, when subtracted from the predicted average journey time for non-priority vehicles, gives an estimate of the journey time for buses. This approach is likely to lead to a degree of underestimation in the time saved by buses, as the term N_s reflects the maximum number of vehicles encountered by a bus rather than the average (as output by TRAFFICQ and CONTRAM). The underestimation may be small in many cases where the setback is short and/or savings are substantial. In any case, it is offset by the overprediction in bus savings (typically of 10%) resulting from the exclusion in equation 7.1 of the time taken by buses to cover the queue distance. This was excluded to maintain compatibility with CONTRAM calculation methods (i.e. predicted journey time is made up from delay plus <u>cruise time for the whole link</u> regardless of queue length) and because predicted bus savings using this method agreed well with those measured (e.g. Figure 8.6). However, a more accurate estimate of the delay to buses could be obtained by graphical/analytical means as illustrated in the example in Appendix C.

An alternative method of calculating bus journey times postulated was to consider the combined use of the queue length/journey time distributions to determine the proportion of the simulation 'counts' in which the queue length exceeded the effective setback distance. Average journey time for buses could then be calculated excluding these occurrences. This has the appeal that full use is made of the detailed modelling, rather than using averages, but relies on the approximation that queue length and journey time are linearly related. However, a further, more serious, problem recognised with this approach was that of a bias towards low predicted journey times for buses, these being based on journey times of vehicles with higher than average speeds. For example, if the queue exceeded the setback distance for 90% of the time, then the average journey time for buses, based on the average of the journey time distribution 'cut off' at 10%, would be made up from those vehicles travelling fastest - it is possible that the average journey time so calculated could be lower than that predicted by the cruise speed, which would be unrealistic. The problem is caused by the modelling of vehicles with different cruise speeds and would only be overcome by specifying a zero standard deviation for vehicle cruise speeds, which would defeat a primary purpose of TRAFFICQ's simulation. This method was therefore abandoned.

For links where no setback is provided (e.g. link 11 in Figure 7.6) the bus lane may be modelled as a separate link to obtain the journey time for buses directly. (Alternatively, the same network in Figure 7.6 could be re-run using a single lane and bus flows only on link 11 to obtain average bus journey times, thus avoiding the need to code a more complex network.)

7.1.2 <u>Contra-Flow Bus Lanes</u>

The modelling of contra-flow bus lanes using TRAFFICQ required the inclusion in the model of all links on the non-priority traffic route(s) and all other links that may be affected by the contra-flow system. The problems associated with the modelling of short setbacks which can occur with with-flow bus lanes (as described in Section 7.1.1 above) do not apply to contra-flow lanes as no setback area is required. The main problem modelling these systems with TRAFFICQ is that traffic assignments have to be estimated externally, which may be difficult particularly for the 'without' bus lane case where a choice of routes exists, and variations in signal timings which are likely with different assignments also require external assessment. With these difficulties in mind, limited modelling of the three contra-flow bus lanes surveyed was carried out using TRAFFICQ as described in Section 8.

7.1.3 <u>Input/Output</u>

The main data input requirements for running TRAFFICQ are listed in Table 7.2 together with those for the other models assessed. This table also shows the values of the non site-specific parameters (e.g. simulation increment, vehicle dimensions, etc.) that have been used in the model.

The output from TRAFFICQ includes:

(i) Queue length distributions for specified links

(ii) Information on the variation of queue length with time for different traffic streams for specified links
(iii) Journey time distributions for specified links
(iv) A summary of mean travel times for each link
(v) A matrix of cross-cordon travel
(vi) An average trip matrix for the modelled period, together with summaries of flows entering and leaving each link
(vii) Predictions of the average fuel consumption per link.

A sample output from a TRAFFICQ run is given in Appendix B.

7.2 CONTRAM : DESCRIPTION AND SENSITIVITY TESTS

CONTRAM (CONtinuous TRaffic Assignment Model) is a computer-based traffic assignment model developed by T.R.R.L. for use in the design of traffic management schemes. It can model vehicle routes, flows, queues and associated parameters in networks containing up to 200 uni-directional links although this number can be increased if required. Vehicles are grouped into packets and assigned to minimum journey time routes through the network using an iterative procedure. The main features of CONTRAM are that it:-

- Models signal controlled junctions (allowing either fixed time signal settings or settings optimised by the program to be used) priority junctions, roundabouts and bottlenecks at merges.
- Represents variations in traffic conditions with time (using time dependent queueing theory), particularly where demand temporarily exceeds capacity.
- Allows for blocking back effects where a queue from one junction fills a link and restricts the capacity of an upstream junction.
- Bans selected movements (e.g. prohibiting access to selected streets for any or all of the vehicle classes) and includes a fixed route option for modelling bus services, for example.
- Estimates fuel consumption for each class of vehicle.

The main data requirements for the model are the physical characteristics of the network including full details of link and junction dimensions, origin-destination vehicle movements through time and control data such as signal timings. Output includes such information as traffic flows, journey times, queue lengths and delays at varying levels of detail, ranging from information for individual links for each time period to summaries covering the whole network over the full modelled period.

CONTRAM, like TRAFFICQ, is recognised by the D.Tp. and has been used mainly for assessing traffic management schemes in medium to large networks where a complex choice of vehicle routes exists. The program is currently only available for use on mainframe and micro-computers.

7.2.1 With-Flow Bus Lanes

The modelling of a with-flow bus lane using CONTRAM was initially considered using the network layout shown in Figure 7.7, layout A. This layout is similar to that originally envisaged for use with TRAFFICQ (e.g. Figure 7.1) except that vehicles of different classes can be fed into the system from a single origin and subsequently assigned to specific links as appropriate using the 'banned vehicle' facility (e.g. non-priority vehicles banned from the bus lane, except for illegal users), or the fixed route option. A series of sensitivity tests were then conducted using the data from Site No. 03 (as for TRAFFICQ), to assess the sensitivity of journey time/delay to changes in key input parameters such as saturation flow, demand flow and signal timings. Results obtained were as expected.

Further sensitivity tests considered the effect of varying the packet size: Results would be expected to be less accurate when using a larger packet size, as larger numbers of vehicles are considered as 'one' homogeneous unit, but, within the range of packet sizes considered, reasonably consistent and acceptable results were obtained. (e.g. Packet sizes of 1, 2 and 3 used with otherwise identical data gave journey times of 94, 93 and 89 seconds per vehicle for three runs of a with bus lane situation; 'without' bus lane runs showed a similar effect, so that the difference in journey time due to the bus lane was similar regardless of packet size.)

CONTRAM predicts delay by modelling 'vertical' queues but also checks whether the average queue length at the end of any time period exceeds the maximum storage capacity for the link. (If it does, exit blocking is modelled by reducing the capacity of those upstream links which are affected.) Queues are discharged at a constant rate depending on the capacity of the link, and the build-up and decay of queues during an individual cycle at a signal controlled junction is not therefore modelled. Thus, temporary exit blocking for link 202 (Figure 7.7) which may occur when queues build up during the red period is not considered by CONTRAM, even when the setback is adequate. The modelling of short setbacks, including those at roundabout entries, could therefore be subject to error.

The modelled effects of blocking back from the setback for the layout in Figure 7.7 was assessed by systematically increasing the arrival flows. The results of these sensitivity tests are illustrated in Figure 7.8, where the equivalent journey times for non-priority vehicles on a single link containing a bus lane are also compared (i.e. for a link where no 'artificial' queueing point exists at the end of the bus lane).

The comparisons show that the journey times for non-priority vehicles are consistently higher when they are modelled using two links (layout A) rather than one (layout B) by some 10%. While the difference is not large, modelling using a single link is likely to be more 'correct' as the mechanisms involved within the program for predicting the effects of blocking back, as created here using two links, may have an error associated with them.

It can also be seen in Figure 7.8 that the modelling of bus journey times using layout A became unstable in the example considered. CONTRAM reduced the capacity of the bus lane (due to exit blocking) to such an extent that buses began to experience considerable delay. When this first occurred, the capacity of the lane containing non-priority traffic had been reduced from 1800 to 1384 pcu/hr, while that for the bus lane had been reduced from 1800 to 76 pcu/hr. This is similar to assuming that the bus lane is the minor road at a priority junction blocked by main road traffic, whereas in reality the two streams have equal priority.

The example described above was one in which the setback was sufficiently long to hold all the vehicles that could discharge during a green phase, theoretical capacity therefore not being reduced. Where this is not the case the stepped saturation flow profile which occurs (see Figure 7.3) cannot be modelled explicitly within CONTRAM. This was also found to be the case for TRAFFICQ (Section 7.1.1). It is therefore again necessary to input an average saturation flow to represent the true profile, the same drawbacks as described in Section 7.1.1 applying. This being the case, there is no advantage in representing the setback as a separate link (as in layout A). The disadvantages of doing so as described above therefore led to this layout option being discontinued, the simpler layout B being generally adopted. This layout was enhanced at each site as necessary to include such features as pelican crossings, upstream junctions and consecutive bus lane links. An example of such a layout is given in Figure 7.6. Pelicans were modelled as in TRAFFICQ, (Section 7.1.1) except that different signal timings were able to be input for each interval in the modelling to reflect variations in the frequency of call and use of the flashing amber period by pedestrians.

The modelling of roundabouts within CONTRAM is based on the entry capacity formulae given in LR942[23] in which the entry capacity is related to the circulating flow and key geometric parameters of the entry and roundabout itself. Capacity prediction is the same as in TRAFFICQ and a similar approach has therefore been adopted to the modelling of the effect of a bus lane on entry capacity. This approach, in which the setback is equated to the flared length is discussed along with other possible approaches in later Sections. The evaluation of journey times for buses for the 'with' bus lane case has been undertaken in the same manner as described for TRAFFICQ in Section 7.1.1 (i.e. using equation 7.1 which gives the time saved by buses through overtaking any queue that is longer than the effective setback length).

7.2.2 Contra-Flow Bus Lanes

The modelling of contra-flow bus lanes using CONTRAM was restricted to the three bus lanes of this type considered in the study (sites 15, 24 and 25). The layouts of these contra-flow lanes are illustrated in the Data Base Appendix while their representation within CONTRAM is shown in Appendix B. CONTRAM appeared particularly suitable for assessing a variety of 'without' bus lane alternatives as, for example, the effects of junction alterations on traffic assignments and vehicle delays could be more easily assessed and the model could optimise signal timings if desired. Only a limited range of alternatives could be assessed within the scope of the study, however, as described in Section 8.

7.2.3 Input/Output

The main data input requirements for running CONTRAM are listed in Table 7.2, together with the values of the non site-specific parameters that have been used in the modelling (e.g. vehicle dimensions, packet size, etc.).

Output from CONTRAM is particularly detailed, an example of which is summarised in Appendix B. Of particular relevance to these analyses are the predictions of journey times, delays and queue lengths which are given on a link-by-link basis for each time interval modelled.

7.3 BLAMP

The BLAMP interactive bus lane model[11], was developed within West Yorkshire Metropolitan County Council (WYMCC) by Mr. G.D. Robertson for analysing the practical effect of a bus lane in terms of delays to priority and non-priority traffic. It was kindly made available to the study for evaluation. The aim of the program is to simulate interactively the build up of queues associated with a bus lane and it enables key parameters controlling traffic performance (such as setback distances and saturation flows) to be varied to assess their effect on delays and to obtain maximum benefit from future installations.

BLAMP (Bus Lane Algorithmic Modelling Program) was written in BASIC language for use on a BBC Microcomputer with extended RAM. It models traffic performance in the lanes before the bus lane starts, the lane(s) alongside the bus lane and the lanes between the end of the bus lane and the signal stop line. Each section is subject to a downstream saturation flow which is user input, and queues can interact with those either upstream or downstream. Traffic arrivals and departures are examined every second for each section of road being modelled.

The bus lane link and associated queues are displayed on a VDU and, with the simulation running at around 6 times real time, queues can be seen building and discharging both on a cyclic basis and over the whole peak period. Average bus and car delays are output every cycle (and onto a line-printer if desired) and averages for the whole modelled period are also given.

A useful feature of BLAMP is the facility to interrupt the program at any point during the model operation and alter the value of any of the input variables. This enables variations in factors such as signal timings and saturation flows, perhaps due to downstream exit blocking, to be varied as required. Arrival flows are modelled either as being constant or as varying through time and a randomising factor for traffic flows, approximating to a Poisson distribution, can also be introduced. The way in which queues form upstream of the bus lane and in the setback can also be varied to match observed/expected site conditions.

The basic theory of BLAMP, in terms of model form, queue handling, delay calculations and assumptions concerning lane choice is described fully in Reference 11. The BLAMP[11] program is, at present, restricted to a single bus lane link and does not therefore model such features as the traffic diversions and minor road delays caused by the bus lane. However, the probability of these events occurring can be estimated from the detailed queue length/delay predictions (e.g. it is possible to reduce manually the flow when delay reaches a certain level to estimate the volume of traffic likely to divert). The effect of a pelican crossing or other feature that may reduce the capacity of the lane(s) alongside the bus lane can also be assessed to some extent by reducing the downstream saturation flow for this lane by an appropriate amount.

Where a lane of traffic is subject to opposing flow, it is necessary to adjust the saturation flow to exactly the level that gives the correct number of vehicles exiting in the cycle. In reality, this may vary during a peak period as levels of opposing flow vary, and it may then be necessary to take advantage of BLAMP's facility of halting the program at any point to change the value of selected parameters. It is thought that a similar approach may be applicable to other give-way situations such as at roundabouts, where the model would be run with the green time equal to the cycle time (as in TRAFFICQ).

7.3.1 Input/Output

The data inputs required to run the BLAMP model at a bus lane are given in Table 7.2. Further details are given in the example in Appendix B. Two data input 'menus' have to be specified before each run. The first, the 'user menu', requires details of bus lane geometry (link length, setback length and the number of lanes), signal timings, and arrival flows for buses and cars in selected time intervals to represent the peak period arrival profile. The second menu, called the 'expert' menu, requires details of saturation flows at each of five possible locations on the link and a number of other parameters as shown in the example in Appendix B. The 'Diff in Q' parameter allows the difference in queue for traffic using different lanes in the setback to be specified - this may vary from site to site. Different traffic compositions can be catered for through the 'vehicle length' parameter. The 'merge factor' allows the queueing characteristics (in terms of lane choice) in the lanes leading up to the start of the bus lane to be specified. Finally, traffic arrival flow can be input either as a constant value over each time period, or with a simple randomising factor.

Sensitivity tests carried out using BLAMP showed that delay was affected as expected by changes in parameters such as saturation flows, signal timings and setback distances. However, a full assessment of the sensitivity of delay to changes in all of the input parameters was not possible within the scope of the study.

Results from these sensitivity tests and of the application of BLAMP to a limited number of the study sites are described in Section 8.

7.4 ALTERNATIVE 'WITHOUT' BUS LANE LAYOUTS

Two basic alternative layouts have been considered for the analyses of the 'without' bus lane situation for with-flow lanes:

(i) Removal of the bus lane while maintaining the existing road layout

(ii) Removal of the bus lane such that the link width is decreased by 1 lane width.

In the majority of cases, the bus lane was introduced on a link without any link widening, and the situation (i) above therefore applied to the 'without' bus lane alternative. Three of the with-flow bus lanes, however, were formed by the provision of an extra lane to accommodate buses (sites 04, 10, 12). In this case, the bus lane will clearly give an advantage to buses and may increase the capacity of the downstream junction if a setback is provided. These benefits have to be weighed against the possible considerable additional cost of providing an extra lane. The bus lanes at these sites have therefore been compared both with the original 'without' bus lane alternative, i.e. the existing layout less one lane, and the situation which would occur if the bus lane were removed now, i.e. maintaining the existing road dimensions.

It would also be possible, of course, to evaluate a further alternative, that of allowing the additional lane to be used by general traffic. Such an evaluation may well be required in practice.

Considerable variations are suspected to have occurred in parking/loading characteristics at the bus lane sites before the introduction of the bus lane, and without a knowledge of these conditions it has not been possible to incorporate these variations in the analyses. However, when evaluating an existing link for a proposed bus lane, detailed parking characteristics would be known and would have to be incorporated in the evaluation. For example, if parking/

loading is commonplace, the nearside lane may already be 'lost' for queueing purposes, and the introduction of a bus lane may not lengthen queues, and its effectiveness may be largely related to the degree of compliance to the new parking/loading restrictions. In these analyses it has been assumed that parking/loading restrictions were already in force, so that changes in such factors as queue lengths/journey times are due to the bus lane alone and do not incorporate any effects of changes in parking characteristics.

The 'without' bus lane alternatives at contra-flow sites may be much more numerous than at with-flow sites. Where the system has been introduced to allow buses to avoid a one-way system, 'without' bus lane alternatives may include:

(i) Restricting buses to the same route as general traffic,
(ii) Allowing the 'bus lane' to be used by general traffic (i.e. giving a choice of route),
(iii) Reverting to original/different forms of junction control.

A number of other options are also possible.

For the purposes of this study, alternatives (i) and/or (ii) have been investigated at each of the 3 contra-flow sites, with the option of signal timing optimisation being included to reflect the different traffic assignments occurring for each option. In practice, any individual scheme may require a large number of alternative designs to be assessed.

7.5 TRAFFIC PERFORMANCE IN THE SETBACK

The approach adopted in this study to the assessment of stop line saturation flow at with-flow bus lanes with a setback has been to construct a saturation flow profile representing the discharge characteristics during the green time (e.g. Figure 7.3). With this approach, it is assumed that, once the setback has cleared, the saturation flow is reduced to that which can be discharged from the lane(s) adjacent to the bus lane. It is therefore assumed that vehicles leaving this lane do not reduce their headways in the setback before reaching the stop line (e.g. by moving into the nearside lane and accelerating faster than vehicles in front). This typically leads to an optimum setback distance in metres of some 2.75g under saturated conditions (where g = effective green time in secs) assuming the proportion of green time is such that there is a sufficient supply of vehicles to keep the setback full.

The queueing and lane choice behaviour assumed in the simulation model developed by T.R.R.L. from which their recommendations in LR809[6] were based, is that:

- When the green period commences, new arrivals only enter the nearside lane if the queue in the offside lane(s) is not as far back as the end of the setback and then at a rate which does not allow the queue in the nearside lane to become longer than that in the offside lane(s).

This differs somewhat from the earlier description of the computer simulation developed at T.R.R.L., described in LR 609[24], and from the performance characteristics described above, although it is unclear to what extent vehicles leaving the lane adjacent to the bus lane and joining the nearside lane in the setback are assumed to close up on the vehicle ahead. Nevertheless, the recommendations concerning optimum setback distance under saturated conditions are only slightly lower than those determined above (around 2.5g compared with 2.75g).

The BLAMP model, on the other hand, allows the effects of vehicle use of the nearside lane of the setback during the green period to be investigated. The other extreme to assuming no vehicle use of this sort (as in the 'profile' method above) is to assume that alternate vehicles move into the nearside lane of the setback and close up on those ahead. No reduction in capacity then occurs while there is a queue in either lane.

The differences in the approaches can have a significant effect on the predicted effects of a bus lane, as illustrated in the following simple example where straight ahead only traffic is considered:

Setback length = 30m, containing 5 pcus
Number of traffic lanes at the stopline = 2
Saturation flows = 1800 pcu/hr for all lanes
Cycle time = 40 secs, effective green time = 20 secs

<u>Method 1 - Saturation Flow Profile</u>

10 pcus in setback discharge in the first 10 secs of green.
5 pcus can then discharge in following 10 secs

∴ 15 pcus discharge in each 20 second green time, giving a saturation flow of 2700 pcus per hour. This represents a 25% reduction on the saturation flow which could be achieved without the bus lane (3600 pcu/hr). The optimum setback should allow 20 pcus to discharge per cycle (i.e. it should hold 10 pcus in each lane and therefore be 60m long as, in this example, queued pcus headways equal 6m). The optimum setback in this example is therefore 3g.

Method 2 - Full Use of Setback and Move-Up Ability

This is best illustrated by following the queue lengths in each lane of the setback during the green period:

Time (secs after start of effective green)	Setback Arrivals (pcus)	Setback Departures (pcus)	Queue (pcus)	
			Lane 1	Lane 2
0	0	0	5	5
4	2	4	4	4
8	2	4	3	3
12	2	4	2	2
16	2	4	1	1
20	2	4	0	0

This sequence shows that the queues in either lane do not fully discharge until the end of the effective green period, and 20 vehicles depart in this time. Capacity is therefore unaffected by the bus lane, being maintained at 3600 pcu/hr, the optimum setback distance being 1.5g. It is worth noting that vehicles further back in the queue have further to 'move up', so that the last vehicle (vehicle 20) is effectively assumed to clear the junction at the same time as it leaves the lane adjacent to the bus lane.

These different assumptions concerning traffic performance in the setback can clearly lead to different interpretations of the effects of the setback distance on capacity and delay. The facility within BLAMP to look at a range of options (or to 'calibrate' this feature to existing conditions) is useful in this respect. Site observations in this study have suggested that during the green period most drivers remain in the outer lanes(s) provided there is not an opposed right turn movement. The 'profile' approach described above should therefore normally only contain a small bias towards low saturation flows.

TABLE 7.1 : SENSITIVITY OF JOURNEY TIMES PREDICTED BY TRAFFICQ TO CHANGES IN SIMULATION INCREMENT FOR TWO ALTERNATIVE LAYOUTS

VEHICLE TYPE	NETWORK LAYOUT	SIMULATION INCREMENT	PREDICTED AVERAGE JOURNEY TIME (SECS)		ADVANTAGE OF BUS LANE (SECS)
			WITH BUS LANE	WITHOUT BUS LANE	
Non-Priority	Fig. 7.1	3	43	40	-3
		4	46	38	-8
		5	55	55	0
		6	70	47	-23
Buses	Fig. 7.1	3	43	40	-3
		4	44	38	-6
		5	55	55	0
		6	68	47	-21
Non-Priority	Fig. 7.2	3	36	35	-1
		4	39	37	-2
		5	42	39	-3
		6	40	39	-1
Buses*	Fig. 7.2	3	35	35	0
		4	37	37	0
		5	39	39	0
		6	39	39	0

* Calculated from output from non-priority 'runs' (see Section 7.1.1)

TABLE 7.2 : MAIN INPUT REQUIREMENTS FOR MODELS

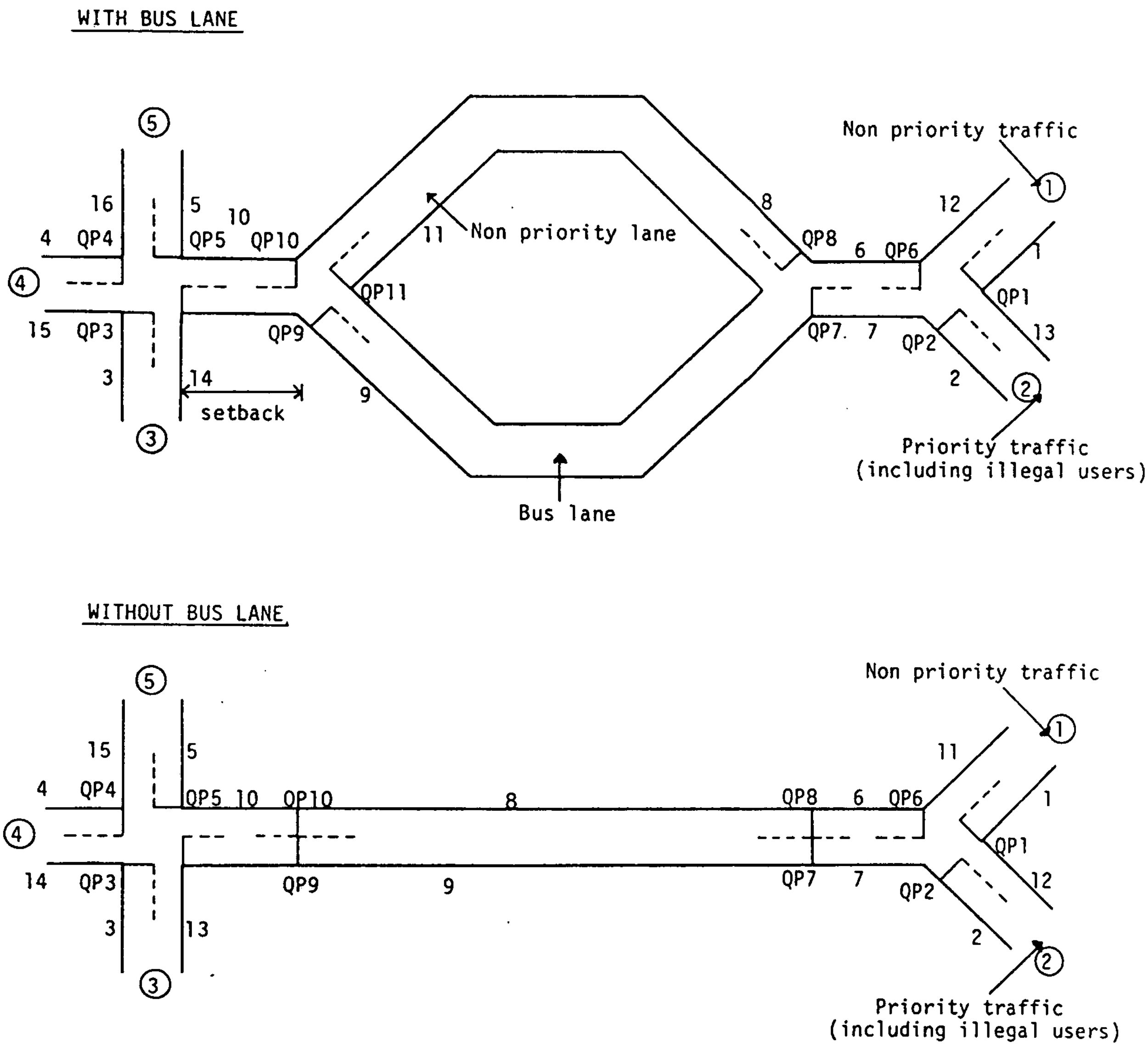
ITEM[1]	MODEL[2]		
	TRAFFICQ	CONTRAM	BLAMP[4]
Main Parameters			
Link lengths	*	*	*
Number of lanes	*		*
Storage capacity of link		*	
Vehicle dimensions	*	*	*
Roundabout geometry (if applicable)	*	*	
Vehicle routes	*		
Origin-Destination traffic flows	*	*	
Arrival flows			*
Flow profile	*	*	*
Cruise time/speed	*	*	
Saturation flows	*	*	*
Form of signal control ∇	*	*	
Signal timings	*	*	*
Specifications, Ranges, etc.			
No. of section lengths for link	3	1	3
No. of vehicle classes	1	3	2
Maximum number of links	~60	200	1
Maximum number of vehicle routes	2	∇	1
Number of saturation flow inputs per link	2	1	4
Maximum number of time intervals for model	6	12	>15
Values of other parameters used in modelling			
Simulation increment (secs)	3		
Vehicle packet size		1 or 2	
Queued vehicle headway-cars (m)	5.5*	5.5*	5.5*

1 ∇ : Fixed time (linked or unlinked) or vehicle actuated for TRAFFICQ
: Fixed time or optimised cycle time/green splits for up to 12 time periods for CONTRAM
: Fixed time for BLAMP, changed at any time during modelling

2 : Model containing parameters listed are marked *
∇ = only restricted by network layout

* From observations and as recommended in TRAFFICQ. However, in traffic streams containing 'significant' proportions of commercial and public service vehicles, a vlaue of 6.0m may be more appropriate.

FIGURE 7.1 : SIMPLIFIED EXAMPLE OF A METHOD OF MODELLING THE 'WITH' AND 'WITHOUT' BUS LANE NETWORK USING TRAFFICQ

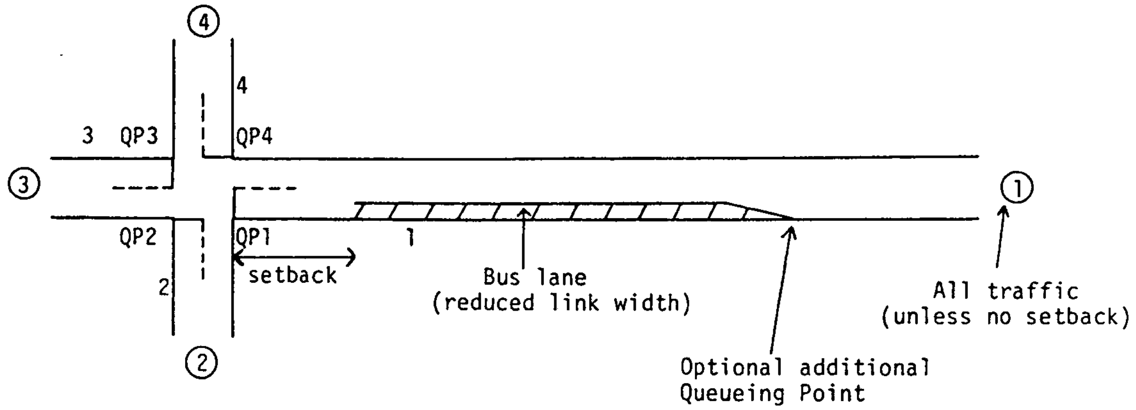


Circled numbers are cordon points
Other numbers are link numbers
QP : Queueing Point

Note : For clarity these layouts exclude upstream junctions, side road, pelicans etc.

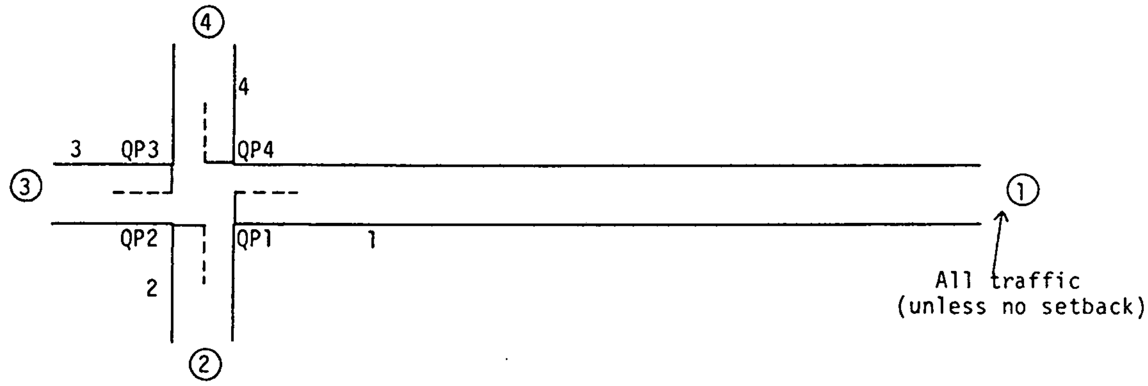
FIGURE 7.2 : SIMPLIFIED EXAMPLE OF A METHOD OF MODELLING 'WITH' AND 'WITHOUT' BUS LANE NETWORKS USING TRAFFICQ

WITH BUS LANE



Note : This layout models the disbenefit (if any) to non priority traffic
The benefit to priority vehicles is calculated subsequently.

WITHOUT BUS LANE

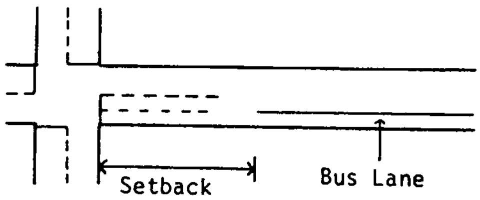


Circled numbers are cordon points
Other numbers are link numbers
QP : Queueing Point

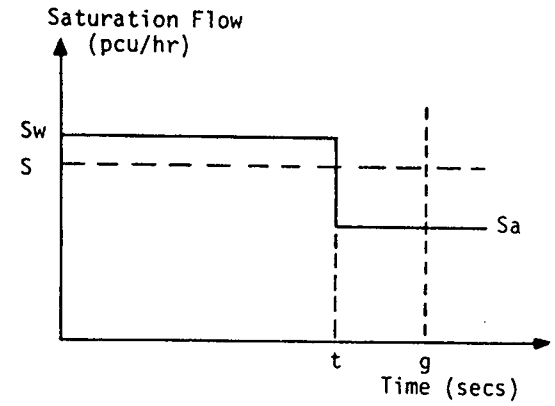
Note : For clarity these layouts exclude upstream junctions, side roads, pelicans, etc.

FIGURE 7.3 : EXAMPLES OF CALCULATION OF AVERAGE STOP LINE SATURATION FLOWS(S)

LAYOUT A PARALLEL ENTRY



$$S = \left[S_w t + S_a(g-t)\right]/g$$



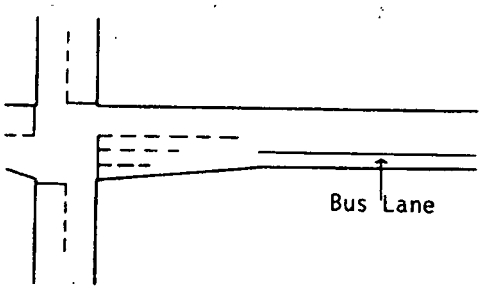
Sw = maximum stop line saturation flow (pcu/hr)

Sa = saturation flow from lane adjacent to bus lane (pcu/hr)

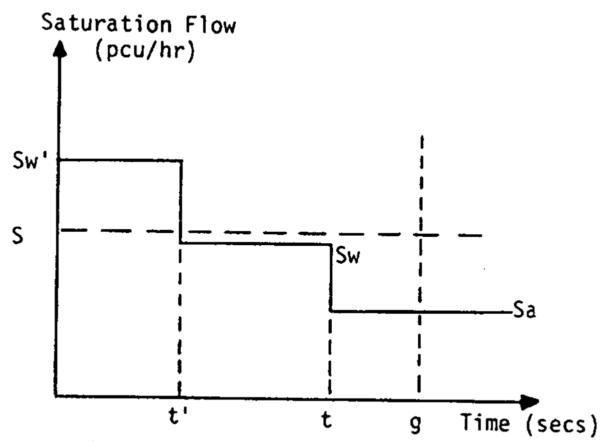
t = time for setback to clear (secs)

g = effective green time (secs)

LAYOUT B FLARED ENTRY



$$S = \left[S_w' t' + S_w(t-t') + S_a(g-t)\right]/g$$

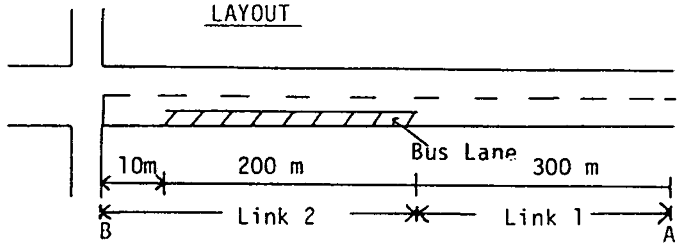


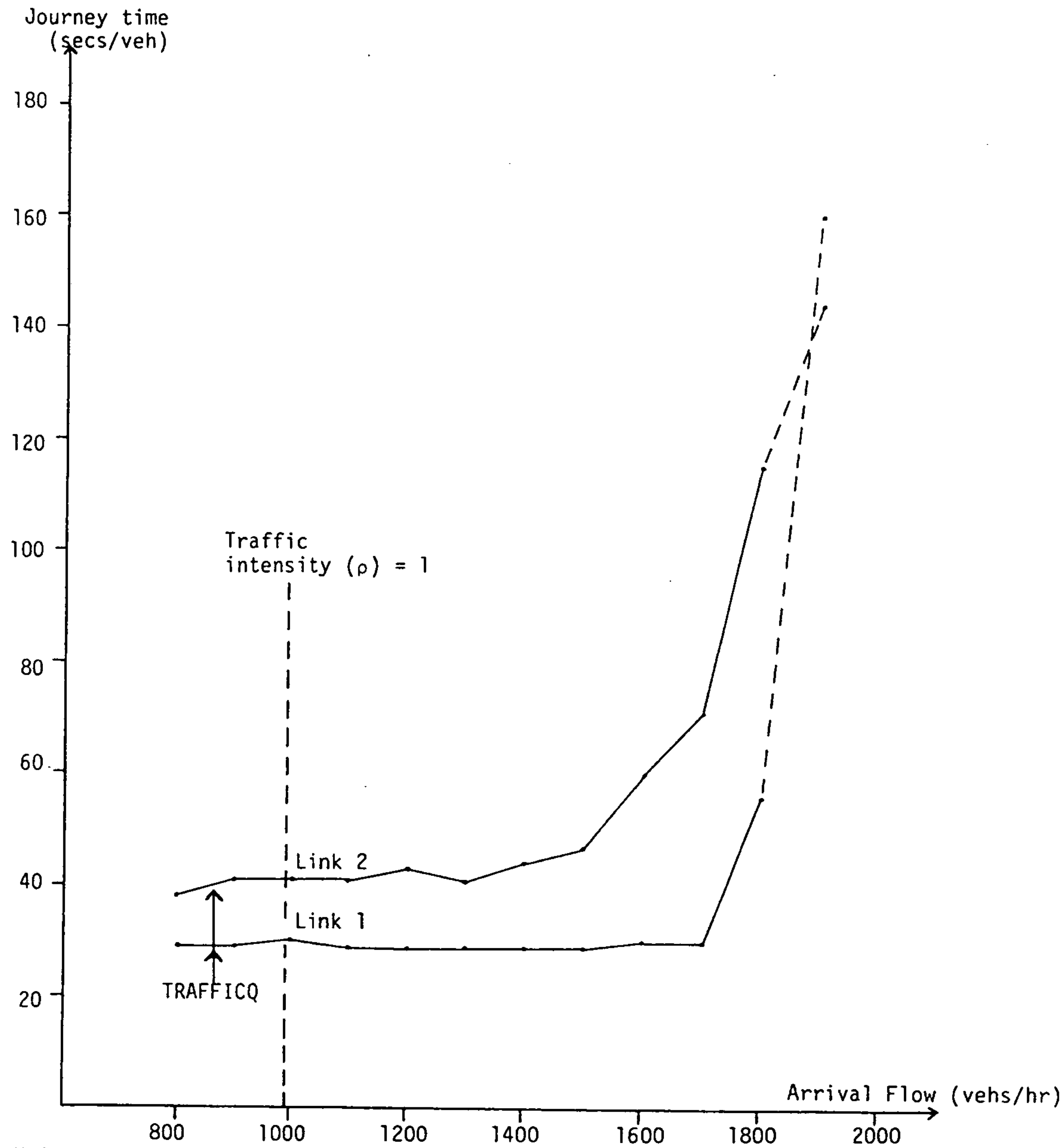
t' = time for flare to clear (secs)

Note : In both cases, if $t > g$, bus lane does not reduce saturation flow

FIGURE 7.4 : EXAMPLE OF THE RELATIONSHIP BETWEEN JOURNEY TIME AND ARRIVAL FLOW PREDICTED BY TRAFFICQ*

Stop line sat flow = 3600 pcu/hr
λ = 0.5 [Green time = 50 secs]
[Cycle time = 100 secs]





* Using a typical 2 lane saturation flow on a bus lane link with a short setback

FIGURE 7.5 : EXAMPLES OF PREDICTED EFFECT OF FLARED LENGTH ON ENTRY CAPACITY AT ROUNDABOUTS

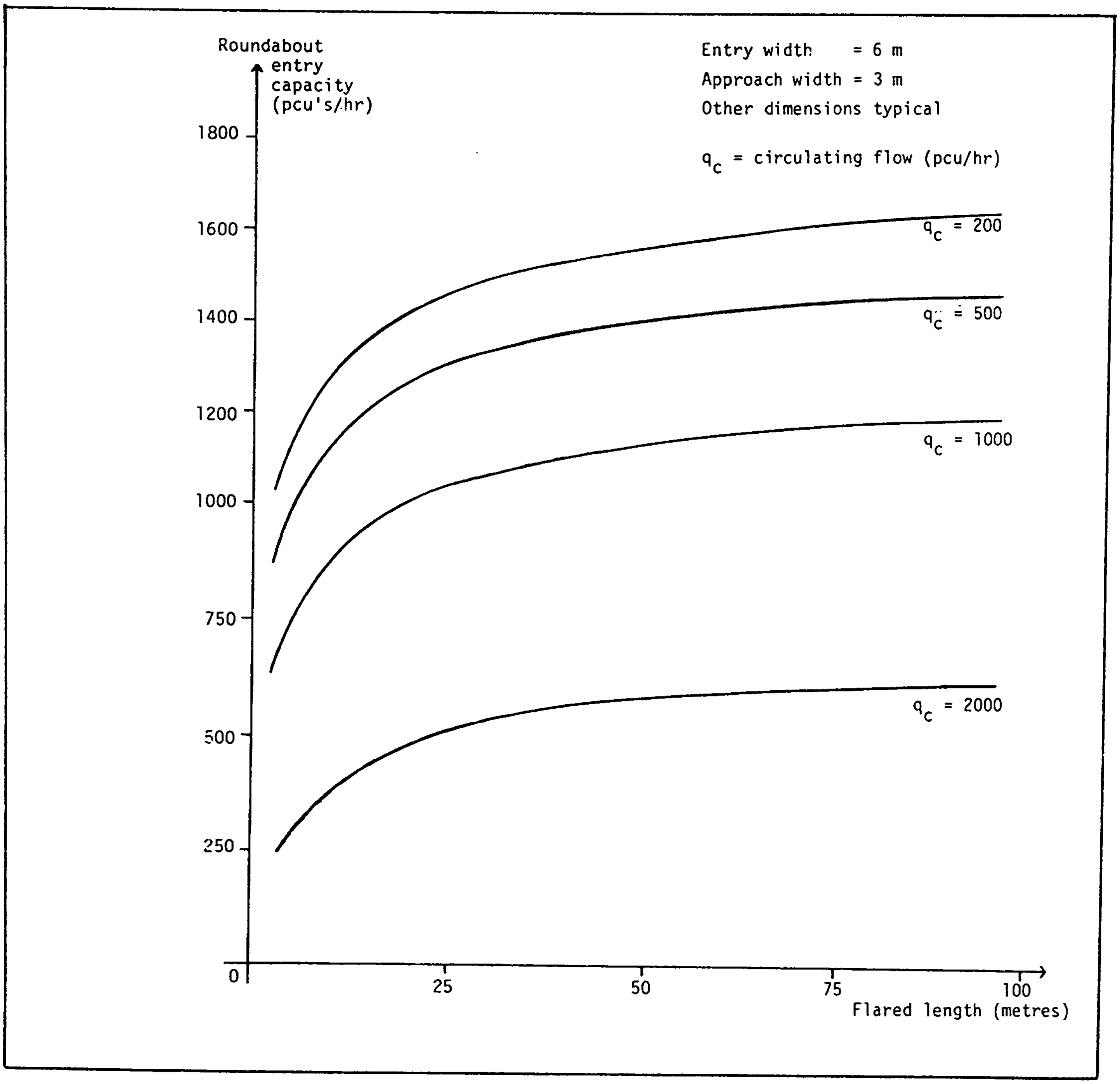
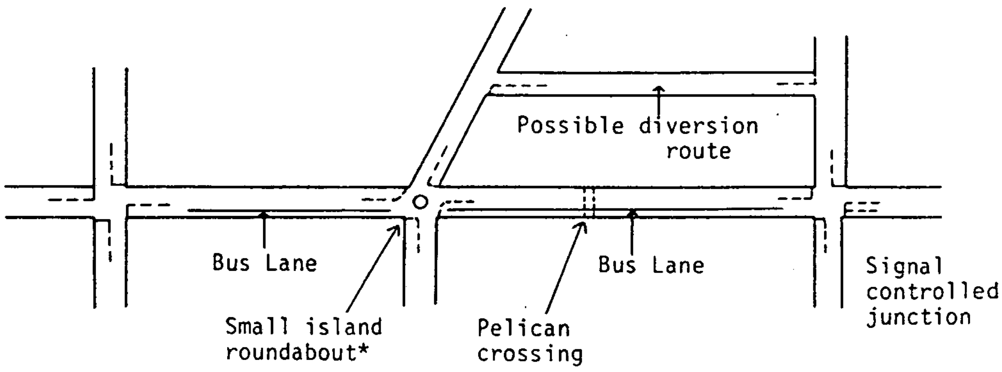
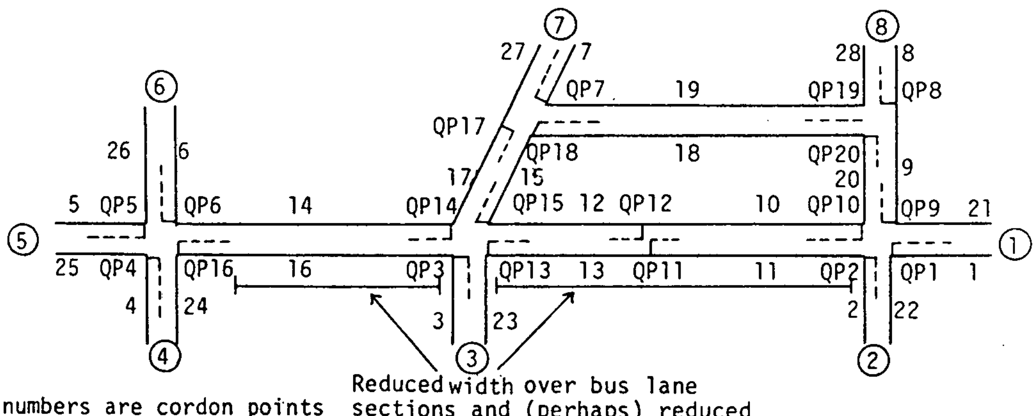


FIGURE 7.6 : EXAMPLES OF NETWORK LAYOUT FOR CONSECUTIVE BUS LANE LINKS SHOWING TRAFFICQ AND CONTRAM CODING : EFFECTS ON NON-PRIORITY TRAFFIC



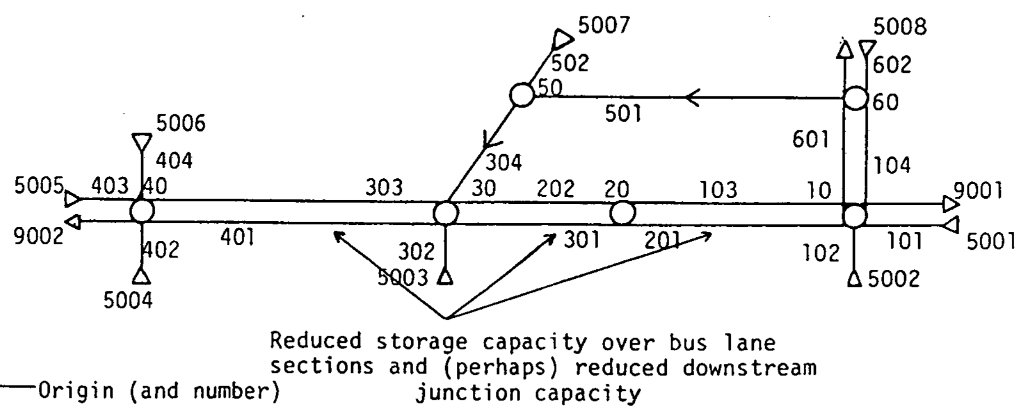
TRAFFICQ CODING EXAMPLE



Circled numbers are cordon points
Other numbers are link numbers

QP = Queueing Point

CONTRAM CODING EXAMPLE **



▷—— Origin (and number)

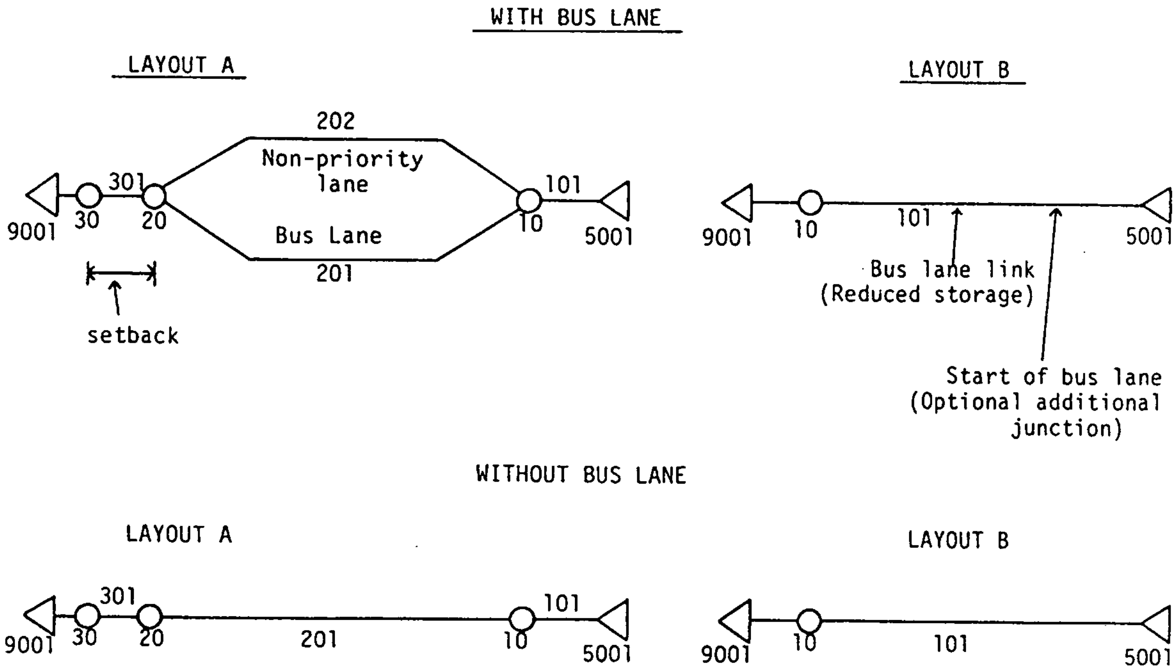
◁—— Destination (and number)

○ Junction (and number) —— Link (and number)

** Additional destination links may be modelled as necessary (e.g. for traffic turning off the bus lane link)

* Larger conventional roundabouts would require each weaving section to be modelled as a separate link in both TRAFFICQ and CONTRAM

FIGURE 7.7 SIMPLIFIED EXAMPLES OF METHODS OF MODELLING 'WITH' AND 'WITHOUT' BUS LANE NETWORKS USING CONTRAM

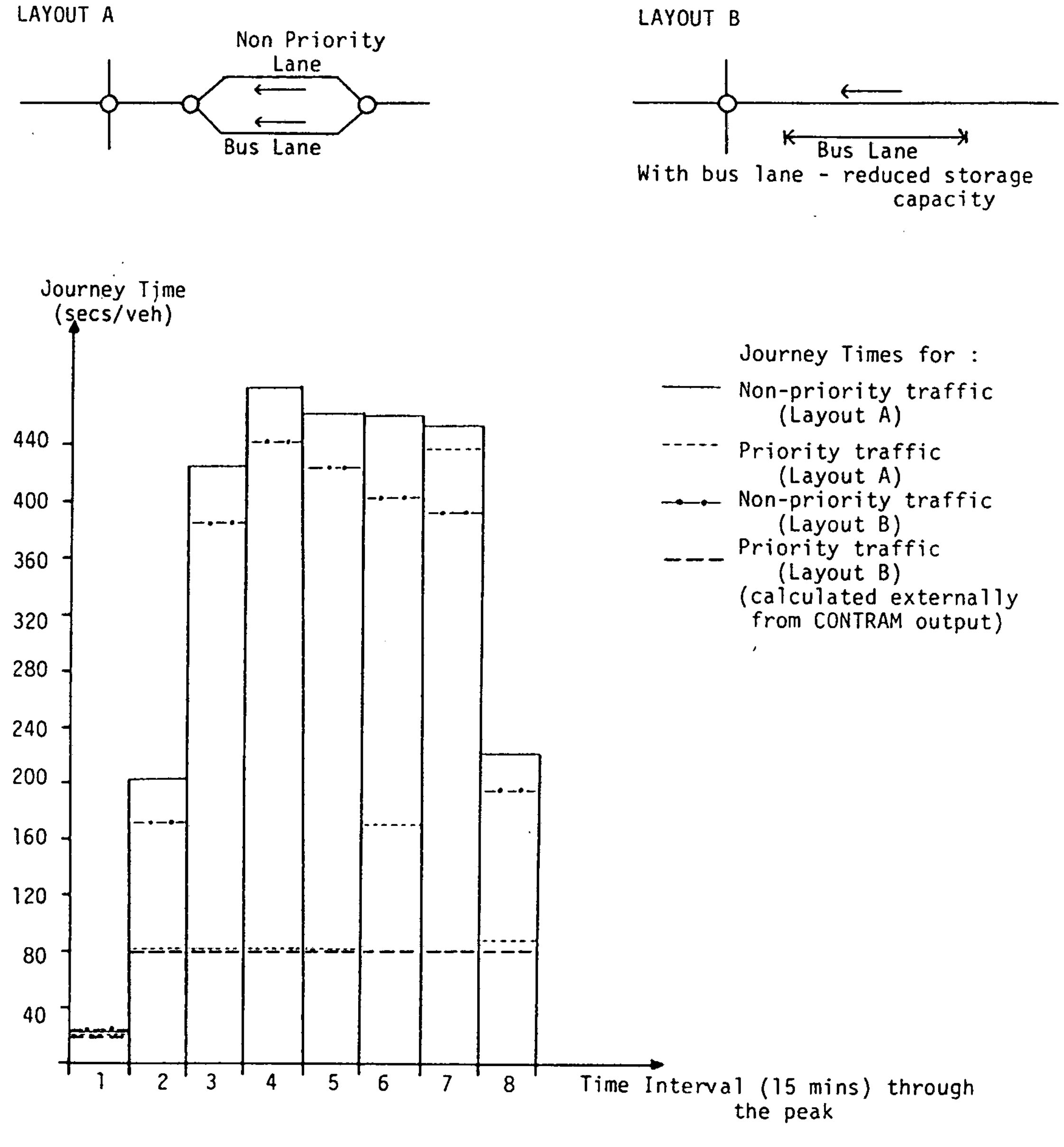


Note : For clarity, these layouts exclude upstream junctions, side roads, pelicans, etc. and only model movements on the bus lane link in the direction of interest


: Junction (2 digit junction number beneath)

: Link (3 digit link number beneath)

FIGURE 7.8 : EXAMPLE OF PREDICTED JOURNEY TIMES FOR PRIORITY AND NON-PRIORITY VEHICLES USING CONTRAM WITH TWO ALTERNATIVE LAYOUTS



Note : The same stopline saturation flow has been used for all trials

SECTION EIGHT

COMPUTER MODELLING : RESULTS

8.1 SENSITIVITY TESTS

Before applying the three computer models TRAFFICQ, CONTRAM and BLAMP to the survey sites, further sensitivity tests were undertaken to compare delay predictions from each model when traffic intensity (the ratio of traffic demand to capacity (ρ)) was systematically increased at a site. The results are illustrated in Figure 8.1. The form of the relationship between delay and traffic intensity is similar between models. At lower intensities ($\rho<0.5$) CONTRAM predicted lower delays that the other two models, by around 25%. Of greater interest however, are the results when ρ approaches and exceeds 1. When ρ is 0.9, CONTRAM and TRAFFICQ predicted the same delay, with the BLAMP prediction some 27% lower. However, when demand equalled capacity throughout a peak period, widely different results were obtained from the models. For $\rho>1$, all models predicted sharply rising delays as expected.

The time after the start of modelling that the queue exceeded the bus lane length was also noted for the three models for the condition $\rho=1.1$ to assess blocking back predictions. These times, listed in Figure 8.1 also show substantial variation.

The results in Figure 8.1 indicated that, for traffic intensities around 1.0, considerable variation may be expected in delay and queue length predictions between the three models, although it is not possible to determine which of the three models is most realistic. (Very detailed on-street observations would be required for this.) There is no evidence from this analysis to prefer or reject any of the models.

Although a number of theoretical relationships between delay and traffic intensity have been developed there is still considerable uncertainty in this area. At one extreme, steady state theory predicts an infinite delay when traffic intensity is 1.0, while at the other extreme, deterministic theory predicts zero delay until traffic intensity reaches 1.0. More recently developed time dependent queueing theory results in a 'compromise' relationship between these two extremes, and this approach has become widely adopted. It should be noted that the simulation studies at T.R.R.L. were based on steady state theory (as in TP56[16]) and therefore only applied to undersaturated conditions. Of the models considered here, CONTRAM uses time dependent queueing theory. TRAFFICQ's microscopic simulation would be expected to predict delays closer to the time dependent queueing approach.

8.2 MODELLING THE 'WITH' BUS LANE SITUATION

The two computer models, CONTRAM and TRAFFICQ, were first run for each survey at each site using the data inputs given in Table 7.2 together with measured information for the survey day. Modelling of each survey was necessary as a detailed comparison was required of observed and predicted results: Day-to-day variations in such factors as traffic flows and delays could lead to apparent inaccuracies in the models if the data for the various survey days were combined before running the model. (For example non-priority traffic flows varying by only 5% on separate days may produce widely different delays, and a single 'run' using an average flow may result in a predicted delay significantly different from the average of the two days, due to the non-linearity of the flow-delay relationship.)

The saturation flows at signal controlled junctions used in the initial run for each survey were obtained using predictive formulae described in Reference 17 which were developed at Southampton University and are contained with T.R.R.L.'s new OSCADY[15] program. These formulae were based on measurements at 'clean' sites (e.g. where factors such as parking, pedestrian movements and exit blocking were minimal) and therefore predict average saturation flows under ideal conditions. Although such conditions did not apply at many of the bus lanes surveyed, it was felt valuable and necessary to apply these values as a first step. This would give a consistency of approach between sites and highlight the circumstances where site specific measurements of saturation flow would be desirable/essential.

One of the features used in CONTRAM was that turning movements and saturation flows could not be specified on a lane-by-lane basis unless the lane was modelled as a separate link. CONTRAM considers a single entry queue based on the total stop line capacity and demand flow which while suitable for large networks inhibits detailed modelling of individual links. There are a number of occasions when different discharge rates and associated queueing characteristics in each lane need specific assessment to ensure an optimum setback design has been achieved for the bus lane (e.g. too short a setback coupled with an offside lane of opposed right turning traffic could prevent following through traffic from discharging efficiently from the nearside lane). The BLAMP model overcomes this to some extent as, although turning movements are not specified, lane specific flows are. The new OSCADY model soon to be released by T.R.R.L. would be better in this respect.

While both right and left turn only lanes can be modelled as separate links over their length, the modelling of short links in this way by creating artificial junctions is not recommended. However, the restriction of a lane to a single turning movement can reduce the capacity of the entry if, for example, turning demand is low but through traffic demand is high. This is typically the case where the nearside lane in a setback is restricted to left turn only vehicles, perhaps because of a continuing bus lane downstream. The calculation of total stop line saturation flow in this circumstance has therefore been based on the calculated maximum queue of left turners (see Appendix C) where this is less that the setback length.

TRAFFICQ, while also requiring a total stop line saturation flow to be input, can model different turning characteristics by careful use of the downstream link entry saturation flow. Examples of the way in which this is achieved are given in Appendix D. However, the effect of introducing a bus lane with a short setback still requires either the stop line or link entry saturation flow to be adjusted externally (e.g. as in the example in Appendix D).

When modelling the bus lane link as in Figures 7.2 or 7.7, it was also necessary to check that the entry capacity was less than that for the link adjacent to the bus lane. If not, perhaps because of inappropriate setback lengths or signal timings, this latter capacity was used at the entry. This occurred only on a minority of occasions.

The effects of a bus lane on queueing behaviour and associated delay for the different layouts, and the way in which they were modelled is described further in Appendix D.

8.2.1 Results

The results of the initial modelling using TRAFFICQ and CONTRAM are given in Table 8.1, where observed and predicted average journey times for non-priority vehicles can be compared for each survey.

Further illustration of these results is given in Figures 8.2 and 8.3 where the performance of the two models using theoretical 'ideal' saturation flows may be assessed. In general, CONTRAM underpredicted average journey times when measured journey times were high due to congestion, indicating that the predicted saturation flows were too high in many cases. A similar pattern is seen with TRAFFICQ for signal controlled links, although there is more variation in predicted journey times. Two of the roundabout controlled links (Site Nos. 4 and 14) gave particularly high predicted journey times using TRAFFICQ. These TRAFFICQ results were necessarily based on one run of the model in each situation due to the time involved in modelling. In practice, a number of runs would be required (depending on the degree of congestion) with different random seeds to obtain a representative comparison.

Included in Table 8.1 are the average journey times for non-priority vehicles predicted by BLAMP at 6 sites where this model was evaluated. (These results were obtained from running BLAMP with a non-random arrival flow, as the randomised option occasionally gave unstable comparisons between the 'with' and 'without' bus lane situations, and assuming full use of the setback.) These are compared with equivalent figures from CONTRAM and TRAFFICQ in Figure 8.4. It should be reiterated that these results apply to theoretical saturation flows calculated without reference to queueing behaviour or exit blocking, to assess the importance of these factors (which are difficult to quantify) in the evaluation.

8.2.1.1 Calibration

It was clear from Table 8.1 and Figures 8.2 to 8.4 that, in many cases, the initial predictions of journey times could not be used accurately to assess benefits/disbenefits of the bus lane. For this to be achieved the predicted average journey time for non-priority vehicles should be statistically similar to that measured. Apart from any shortcomings of the models themselves the main reasons for inaccurate modelling were considered to be errors in one or more of the following:

- (i) saturation flows/capacity
- (ii) cruise speeds
- (iii) signal timings
- (iv) demand flows.

Predictions of saturation flow or roundabout capacity could clearly be in error as detailed on-site measurements were not generally made. Errors in cruise speed should be small as measurements were made on site, although small errors could have a marked effect on average journey times under unsaturated conditions, particularly on links with long bus lanes. Detailed measurements of signal timings were recorded in the surveys although where considerable variation occurred in green times and/or cycle times these variations are unlikely to have been adequately catered for in the modelling. (Different signal plans reflecting average conditions for each time interval were used in CONTRAM, whereas average timings for the whole survey period were required with TRAFFICQ, unless the "vehicle actuation" option was selected.) Demand flows were either recorded directly (usually at the start of the bus lane) or were estimated by factoring the total stop line flow by the number of vehicles recorded in each time interval in the registration number survey at the start of the bus lane (such vehicles should have been a fixed percentage of the total flow, assuming none were missed). Accurate measurement of demand flow is difficult, however, particularly when queues build upstream of the measurement point or intermediate 'sink or source' flows are significant. Such errors could well have been significant at some sites but were largely unavoidable.

From the considerations above, it was clear that the parameter most likely to be in error and which may be able to be realistically 'calibrated' was the saturation flow. This was known to be in error at a number of sites where packing factors in the setback were low or exit blocking occurred. At a number of sites it was subsequently found/assessed that the bus lane was not reducing junction capacity, and that a simpler form of analysis (other than modelling) was appropriate (as described in Section 6.2). However, it was still considered worthwhile to calibrate the computer models at these sites, particularly to assess the accuracy of the journey time prediction for priority vehicles.

Where a model does not accurately reflect existing conditions further on-site observations would normally be made to try and determine the cause of the discrepancies. Reasons may be numerous, but are often likely to be related to saturation flows (e.g. intermittent exit blocking may temporarily reduce saturation flows or a right turning movement may cause more disturbance than expected). Such assessments would be easier for a Highway Authority familiar and close to the network under evaluation than has been possible in this study where only two days of observations have been possible at sites located throughout the U.K.

The extent to which saturation flows had to be adjusted to match statistically observed and predicted journey times for non-priority vehicles is shown in Table 8.2 for the three traffic models concerned. Stopline saturation flows were calibrated in CONTRAM whereas either stopline or link entry saturation flows were calibrated in TRAFFICQ, depending on the circumstances (e.g. lane markings, exit blocking conditions, etc.). Also contained in this Table are comments concerning the probable reasons for some of the differences between these and the initially predicted saturation flows, based on records from the surveys. On the few occasions that underprediction occurred, reasons were less certain. At site 1 it is possible that the linking by SCOOT between the signals at either end of the link reduced delay, while at site 3 the effect of the opposed turning movement in conjunction with the bus lane was difficult to model accurately (see Appendix D).

The method of calculating average saturation flow based on the profile (Figure 7.3) would theoretically introduce a bias towards underprediction in cases where the junction was undersaturated (e.g. if the setback was not filled, the discharge rate S_w should be achieved by all vehicles. This potential bias has not been reflected in the results in Table 8.2, however, where initial saturation flow prediction has generally been too high. A further problem occurs at sites with varying green times between cycles as this causes variations in average saturation flow per cycle. This effect has not generally been noticeable in the results, however, as variations in green times were normally low during peak periods. (One exception was at site 7, where occasional short green times implemented by the vehicle actuation system probably caused greater delay to traffic than could be represented in the models.)

'Calibration' of TRAFFICQ was restricted to a sample of peak surveys only, mainly due to the increased difficulty involved in calibrating the model (e.g. a decrease in saturation flow would not always result in an increase in link travel time, even though the correct general trend occurred). Calibrated saturation flows were also associated with those corresponding to one random seed only, time preventing the exercise being repeated with alternative random seeds. In practice, it is strongly recommended that TRAFFICQ be run at least twice with different random seeds to assess the resulting variation in journey time - where this variation is high, further runs would be required to obtain a realistic answer. (The number of runs required could be based on the point at which the standard deviation associated with the mean journey time from a number of runs stabilises.)

The adjustments for TRAFFICQ were similar to those for CONTRAM at signal controlled links, although saturation flows generally had to be higher in TRAFFICQ to give the same average journey time. Differences at roundabouts were more marked, however, with TRAFFICQ requiring noticeably higher capacities than CONTRAM for 'calibration' (e.g. see Sites 04 and 14).

The method of 'calibrating' BLAMP was somewhat different from that of the other two models and consisted of:

(i) Reducing the setback length if necessary to give an effective setback length reflecting the average packing factor (Table 6.3).

(ii) Adjusting the difference in queue parameter to prevent vehicles joining the nearside lane in the setback during the green period (i.e. approximately reflecting observed conditions and those assumed in the 'profile' approach of Figure 7.3).

(iii) Adjusting the stopline saturation flows iteratively until observed and predicted delays were statistically similar.

The results for BLAMP in Table 8.2 therefore only represent step (iii) above, which it was hoped would entail relatively small adjustments.

In the initial modelling of the roundabout (site 14) using BLAMP an average theoretical capacity was used for compatibility with results from the other two models. This capacity always exceeded the arrival flow and BLAMP predicted very low delays. 'Calibration' was attempted initially by using a constant saturation flow equal to the average discharge rate, as recommended in Reference 11. However, with the junction not being continuously saturated, the saturation flow calculated in this way was probably too low, and resulted in an overprediction of delay. Also, in reality the circulating flow varied over the modelled period, resulting in a corresponding variation in saturation flow. Further runs were therefore undertaken using saturation flows specific to each modelled interval, based on the observed discharge rate for those intervals considered saturated. This method proved to be the most satisfactory, allowing observed and predicted delays to be matched.

8.3 MODELLING THE 'WITHOUT' BUS LANE SITUATION

In the 'without' bus lane situation, the saturation flow was generally taken as the value of S_W as shown in Figure 7.3, with the following exceptions:

i) Where the 'calibrated' saturation flow for the 'with' bus lane case was below that which could theoretically be discharged from the lanes adjacent to the bus lane, junction capacity was taken as being unaffected by the bus lane. This occurred at some sites where an exit constriction restricted the road width and/or exit blocking was commonplace, and the queueing behaviour was unaffected by the bus lane. While this assumption was considered realistic, it was also reflected within TRAFFICQ where similar journey times were obtained at a site with exit constriction when modelled in two alternative ways (i.e. firstly with a stop line saturation flow reflecting the exit constriction, and secondly with the exit constriction modelled explicitly by reducing the downstream link entry saturation flow while maintaining a much higher stop line saturation flow).

ii) Where the 'calibrated' saturation flows for the 'with' bus lane case varied from the predicted values, the same absolute difference was applied to the predicted 'without' bus lane values (e.g. if predicted and calibrated values of saturation flow were 3000 and 2500 pcu/hr respectively, the predicted 'without bus lane' saturation flow of, say, 4000 pcu/hr was reduced to 3500 pcu/hr). This assumption was clearly subject to uncertainty, as, if the initial reduction was due to short nearside lane queues created by the bus lane, it should not be applied to the without bus lane situation. On the other hand, if it was due to other site characteristics (e.g. pedestrian activity) then it should. This was one of the main areas of uncertainty in the evaluation.

The assumptions concerning the likely effect of each bus lane on junction capacity are given in Table 8.3, which also shows the junction entry layout for each site, further description of the modelling of these layouts being given in Appendix D.

Modelling the 'without' bus lane situation using BLAMP simply required the removal of the bus lane: Saturation flows did not need to be modified as the effects of, say, an insufficient setback were incorporated within the model (unlike TRAFFICQ and CONTRAM where these effects had to be reflected in the average saturation flow input).

CONTRAM Results

Using the assumptions given above, 'without' bus lane predictions of journey time for all vehicles were obtained initially from CONTRAM for each survey. The results are given in Table 8.4, together with comparisons of 'with' bus lane journey times for priority and non-priority vehicles. For priority vehicles, measured journey times exclude the time involved in stopping at bus stops (including associated acceleration/deceleration effects) to enable a fairer comparison to be made between observed and predicted results. The predicted journey times for priority vehicles were obtained as described in Section 7.1.1 and illustrated in Appendix B.

A comparison of the relative effects of the bus lane on the journey times of priority and non-priority vehicles (Table 8.4) predicted by CONTRAM reveals an anomaly at some sites. This anomaly is that while non-priority vehicles suffer a disadvantage due to reduced junction capacity, priority vehicles receive no benefit. This occurs when the predicted queue length without the bus lane never exceeds that which could fit in the effective setback area. The 'with' bus lane saturation flow predicted from the profile as shown in Figure 7.3 is therefore inappropriate as the arrival flow is insufficient to cause the 'tail' of the profile to occur. Clearly, where priority vehicles receive no predicted benefit from the bus lane, non-priority vehicles cannot receive any disbenefit.

A problem with CONTRAM in this area is that the model works on average queues, and does not therefore represent the build up and decay of queues at signals. Thus, although the average queue may not exceed the effective setback area, the maximum queue may, offering priority vehicles some advantage. The extent of this underprediction is difficult to quantify without detailed analyses of the relationship between average and maximum queue length for each time interval modelled. The situation where the average queue length equals the effective setback storage is likely to cause the greatest underprediction.

A further point to note is that the minimum average queue length predicted by CONTRAM is governed by the 'red' delay, and may not reflect the actual average queue length under low flow conditions. For example, a junction with a signal delay of 10 secs (based solely on the proportion of red time per cycle) and a capacity of 0.5 pcus/sec (i.e. 1800 pcu/hr), CONTRAM would give a queue of 5 pcus regardless of the arrival flow. In this example, the CONTRAM output could not be used to assess the benefit to buses if the setback storage was less than 5.

The anomaly described above applies to any time interval within the modelled period when the predicted queue for the 'without' bus lane case is shorter than can fit into the effective storage area. The results for each site have therefore been examined for this occurrence, and marked accordingly in Table 8.4 to emphasise the uncertainty of the results.

<u>**TRAFFICQ Results**</u>

The 'without' bus lane predictions of journey times for all vehicles using TRAFFICQ are given in Table 8.5 for those sites where calibration was undertaken. Again, comparisons may be made with the separate 'with' bus lane journey times for priority and non-priority vehicles.

At those sites where the bus lane was considered not to have reduced the entry capacity due to condition (i) above, a zero disbenefit to non-priority vehicles is given in Table 8.5. In reality, the bus lane may have caused some disbenefit to non-priority traffic (e.g. to left turners) which should be able to be quantified within TRAFFICQ. However, such disbenefits were generally lower than would be obtained by re-running the model with a different random seed presumably due to the low proportion of left turning traffic on the links which were usually main radial routes. A large number of runs would therefore have been required to confirm these small differences and zero disbenefits have therefore been assumed for non-priority vehicles in Table 8.5 in these circumstances. All results in Table 8.5 were obtained from a single run of TRAFFICQ for each situation, a greater number of runs with different random seeds would be required in practice.

The anomaly described for CONTRAM above of a disbenefit to non-priority vehicles without a benefit to buses also applied to TRAFFICQ, and sites where this occurred - either throughout the modelling period or for any time interval within it - are marked accordingly in Table 8.5.

Although TRAFFICQ models the build up and decay of a queue on a cyclic basis (unlike CONTRAM) only the information on average queues was used to determine the journey time savings for buses with the bus lane (as described in Section 7.1.1). These savings would therefore be underestimated particularly in circumstances where the average queue was equal to or less than that which could fit in the effective setback area but the maximum queue exceeded it.

<u>**BLAMP Results**</u>

Results from the calibrated BLAMP runs with and without the bus lane are given in Table 8.6. The noticeable results in this table are:

(i) The slightly greater effect of the bus lane at site 1 compared to the CONTRAM prediction thought to be more realistic and due to BLAMP's modelling of the cyclic growth and decay of queues.

(ii) The disbenefit to non-priority vehicles at site 3 - this is not reflected in CONTRAM or TRAFFICQ due to the queueing assumptions imposed (see Appendix D). It is not possible at present with BLAMP to restrict the stop line discharge to a single lane.

(iii) The results for the roundabout controlled link (site 14) are unstable. This may be due either to inappropriate data inputs (e.g. measured discharge rates (entry flows) did not always reflect saturated conditions - see section 7.3) and/or a function of the model's performance. Further research on BLAMP's application to the roundabout situation is recommended.

(iv) The much lower predicted benefits for buses at site 16 than observed. (This also occurred during the TRAFFICQ and CONTRAM modelling described above.) Reasons for this are unclear.

8.4 COMMENTS

8.4.1 Roundabouts

The results in Tables 8.4 and 8.5 indicate that considerable disbenefits were apparently occurring to non-priority vehicles at some of the sites controlled by roundabouts. These disbenefits were higher than expected, as even at sites with short setbacks, the bus lane did not appear to be greatly reducing capacity (i.e. even though only one or two vehicles were able or chose to queue in the nearside lane of the setback, high circulating flows generally prevented more than this number of vehicles discharging into a gap at any one time). The predicted losses in entry capacities due to each bus lane varied between 9% and 13% for the four entries concerned (site nos. 2, 4, 9 and 14). Although these reductions appear relatively small, they clearly have a significant effect on delay when the junction is operating at or around capacity.

An alternative method of considering the effect of a bus lane on entry capacity at a roundabout is to examine the gap distributions in the circulating traffic. If this traffic is assumed to have a negative exponential headway distribution, then the probability (P) of a headway (h) being greater than time (t) is given by:

$$P(h \geq t) = e^{-\lambda t}$$

where λ = rate of traffic flow

Thus for λ = 2000 vehs/hr,

$$P(h \geq 4) = 0.11 \quad \text{or } P(h \geq 8) = 0.01$$

The probability of a gap in the circulating traffic exceeding 8 seconds in these circumstances is therefore only 0.01 (or 1%). This gap would typically allow 2-3 vehicles to enter from a single lane minor entry, indicating that a setback length exceeding 3 vehicles would not be worthwhile. However, using LR942[23], a flared length of 3 vehicles would typically cause a loss in capacity of some 20%. Using this approach at the study sites 2, 4 and 14 the probabilities of the setbacks provided being insufficient were 2.0%, 3.5% and 0.7%, respectively, assuming full use of the setback. There is evidence, therefore, that the relationships in LR942[23] may overestimate the effect of a flare in some circumstances, and that the disbenefits to non-priority vehicles in Tables 8.4 to 8.5 are correspondingly overestimated.

8.4.2 Side Road Traffic and Re-Assignment

Journey time information collected during the surveys was restricted to that covering vehicles using the bus lane link, as volumes of traffic emerging from side roads were generally low. (Numerous side roads existed at a number of sites and appropriate measurements would have required a much larger survey team as well as yielding information of limited value.)

Side road flows were only recorded where these were significant. The modelling of side road delays has been assessed for both CONTRAM and TRAFFICQ from results from a 'with' and 'without' bus lane situation with both free running and 'blocked' main road traffic. The capacity of a minor road entry in CONTRAM is based on the magnitude of the main road flow and certain geometric characteristics which, using the latest relationships[14] would not be affected by the introduction of a bus lane while free running conditions on the main road were maintained. (The total main road flow was used as the controlling variable, not the flow per lane.) Predicted side road delay is not therefore affected by a bus lane within CONTRAM while main road traffic is free running.

TRAFFICQ, under these conditions, may be expected to reflect the fact that main road vehicle headways are reduced by the introduction of a bus lane, due to the concentration of traffic into fewer lanes. It would therefore be expected that predicted side road delays would be greater with a bus lane. Such results could not be confirmed from the TRAFFICQ output, however, as variations due to different random seedings exceeded those due to the bus lane for the conditions tested.

However, when main road traffic queues back past a side road - perhaps due to the introduction of a bus lane - CONTRAM models a minor road capacity reduced to below its arrival rate (even if the arrival rate is very low) and large delays accumulate. TRAFFICQ, under these circumstances, allows no minor road vehicles to enter the main road and very long queues and delays can therefore accumulate. (It only allows minor road vehicles 'in' if gaps appear in the major road stream which are greater than the merging/crossing gap acceptance.) Observations suggest that both models - particularly TRAFFICQ - will overestimate minor road delays under these circumstances as minor road drivers are able to accept (or are offered) gaps when the main road traffic starts to move.

Traffic diversions away from the bus lane links which may have occurred due to the bus lane could also not be assessed within the resources of the study (except for alternative routeings applying to contra-flow sites). At most of the with-flow sites, queues either did not fill the bus lane link(s) or immediate alternative routes were not obvious. The modelling of traffic diversions which may have occurred would only have been possible with much more detailed traffic and network information. It should also be noted that the modelling of diversion routes which involve the negotiation of a minor arm at a priority junction, as is typically the case for 'rat runs', may be subject to uncertainty as described above. The potential for modelling diversion effects has been examined within the course of this study for the three traffic models considered in Sections 7.1, 7.2 and 7.3.

8.4.3 <u>Queues Longer than the Bus Lane</u>

The journey times listed in Table 8.4 to 8.6 are those recorded or predicted between the start of the bus lane and the downstream stop line. The comparison with predicted journey times without the bus lane is only valid over the same distance provided queues never extend upstream of the start of the bus lane. Where this occurs comparisons have to be made over a distance at least as long as the maximum queue, otherwise the bus lane may apparently benefit both priority and non-priority vehicles. An example of this situation is shown in Figure 8.5.

Both CONTRAM and TRAFFICQ give information on average queue lengths at regular intervals during their modelling and TRAFFICQ also gives a more detailed queue length distribution. BLAMP shows the detailed growth and decay of queues on a cyclic basis. It was therefore possible to check the output from each model to see whether the queue length ever exceeded the bus lane length, a situation that was observed during part of the surveys at sites 6, 7, 8 and 9. (Slow moving traffic was also observed at the start of the bus lanes at sites 4, 16, 17 and 18 although stationary queues were not recorded.) This investigation showed that predicted queues longer than the bus lane length only occurred at site 6 for CONTRAM and sites 6, 8 and 9 for TRAFFICQ, as shown in Table 8.7. (BLAMP was not run at these sites.) Journey times were then re-calculated for the ' with' and 'without' bus lane cases according to Figure 8.5.

Table 8.7 also contains information on predicted and observed queue lengths. It is noticeable that:

(i) Despite predicted average journey times being matched to those observed, predicted queue lengths were less than expected at sites 6, 9 and (particularly) 7.

(ii) Queue lengths predicted by CONTRAM were always lower than those predicted by TRAFFICQ. This would be expected, due to the operational nature of the two models and confirms the expectation that TRAFFICQ should model varying queue lengths and (potentially) their associated blocking effects better.

These results, although limited to four sites, give an indication of the problems of modelling oversaturated conditions. The extent to which the difficulties lie in the modelling itself or in the inputs to the model is unclear, however.

8.4.4 Priority Vehicle Journey Times and Speeds

The predictions of journey time for priority vehicles for each of these models are compared with measured journey times (excluding bus stopped time) in Tables 8.4 to 8.6. It was found that, in general, journey times predicted by TRAFFICQ and CONTRAM were relatively similar, as may be expected as the same procedure was adopted to calculate these journey times from each model output. Savings predicted by BLAMP were also of the same order of magnitude.

Some differences were noticeable, however, between observed and predicted journey times, as illustrated in Figure 8.6 for the CONTRAM results, and further analysis of these differences was undertaken to try and relate, for example, bus cruise speeds with degrees of bus lane violation. In these analyses, the predicted delay suffered by buses at the downstream junction has been assumed to be correct, and the cruise speed of these vehicles has been re-calculated such that observed and predicted journey times are matched (actual cruise speeds for buses over the whole bus lane length were not recorded in the surveys).

The results of these analyses are given in Table 8.8, where average speeds for buses are given for each site including and excluding junction delays and including and excluding the time spent at bus stops. Average speeds for all sites are also given. Thus, in summary, the average speed of buses including junction delays and the time spent at bus stops was 18 kph. Excluding stops but including junction delay, an average speed of 24 kph was recorded, while including stops but excluding junction delays, the average speed was 26 kph. (The effect of junction delay was therefore, on average, similar to that of bus stops.) The average speed excluding junction delay and stops increased to 38 kph.

The difference in cruise speeds given for each site in Table 8.8 shows the percentage change in cruise speed (from that of non-priority vehicles) that is calculated to apply to priority vehicles. These changes show considerable variation between sites, with cruise speeds often being considerably lower for priority than for non-priority vehicles. Some indication of likely cruise speeds for priority vehicles under different circumstances would clearly be useful for future evaluations and further analyses were therefore undertaken. A number of possible reasons for priority vehicles having reduced speeds were postulated, based on observations from the study sites:

(i) Short bus lane link (i.e. buses unable to accelerate to a cruise speed)
(ii) Frequent bus stops
(iii) High degree of illegal use of bus lane, particularly by stationary vehicles
(iv) Queue of non-priority vehicles for the whole (or most) of the length of the lane adjacent to the bus lane
(v) High flows of pedal cycles
(vi) Uphill gradient.

The quantification of the effects of these factors was difficult from the data available, as most sites contained a combination of these features. The features applying to each site were therefore simply noted in Table 8.8 to give an indication of the scale of such effects.

It is not considered that the bias towards an overprediction of bus journey times inherent in the calculations (as described in Section 7.1.1) has been of significance at the majority of sites.

8.5 ALTERNATIVE 'WITHOUT' BUS LANE LAYOUTS

With Flow Bus Lanes

The results in Tables 8.4 to 8.7 give the predicted benefits/ disbenefits of each bus lane assuming that road geometry remains the same. However, the bus lanes at sites 4, 10 and 12 were formed by the construction of an extra lane, and the 'original' without bus lane alternative therefore contained one fewer lane than at present. This situation has been modelled using CONTRAM for one peak period at these three sites, to illustrate the effects of different 'without' bus lane alternatives. The results of this analysis are given in Table 8.9.

The difference in the predicted 'without' bus lane journey time between layouts 1 and 2 is that brought about by the provision of an extra lane for buses and (for sites 4 and 12) a short setback used by all traffic. Predicted journey times would have been particularly high at site 4 without this provision, although some traffic re-assignment would probably have occurred in practice.

The predicted economic benefits of the provision of an extra lane at these three sites are described in Section 9, where reference is also made to the costs of implementation of an extra lane.

Contra-Flow Bus Lanes

The results of the evaluation of the three contra flow bus lanes (sites 15, 24 and 25) given in Table 8.4 refer to the situation where, without the bus lane, non-priority traffic can use any route between the origin and destination of interest. One simplification made in this modelling is that traffic would not be delayed behind buses stopped at bus stops, which would clearly not be the case were only a single lane available: A small underprediction of non-priority vehicle journey times without the bus lane is therefore inevitable. A (perhaps) more likely alternative is that the one-way system remains in force and buses are directed around it on the same route as non-priority traffic. This alternative has therefore also been assessed at the three study sites. The main difficulty of this alternative concerns the signal staging structure at the junctions at each end of the bus lane. For the purpose of this analysis it has been assumed that the stage arrangements and timings remain as at present for each of the sites as, in each case, the stages were shared with other traffic movements for which provision would have to be maintained.

The results of this modelling are given in Table 8.9, the contra-flow sites being numbers 15, 24 and 25. The modelling has excluded the small benefit which may occur to traffic travelling in the opposite direction to buses if the contra-flow lane was removed ('without' bus lane alternative layout 2). It has also excluded the effects on other traffic from alterations in signal timings within CONTRAM. In practice, both of these effects would need assessment. As expected, at each of the three sites, the bus lane is much more beneficial when compared against alternative layout 2 (the maintenance of the one-way system for all vehicles) than layout 1 (where non-priority traffic is allowed to use the contra flow lane).

The results for site 15, layout 1, indicate that no advantage would be gained by allowing non-priority vehicles a free choice of route. In fact, with this option combined with optimised stage timings, CONTRAM predicted longer overall journey times for all vehicles. Closer inspection showed that, while the existing 'with' bus lane system was working efficiently, at least small benefits should be obtainable with this alternative. (Time precluded a more detailed investigation although the problem is thought to stem from the signal optimisation procedure related to time intervals where demand exceeds capacity, as observed at this site). The zero disbenefit to non-priority vehicles is therefore likely to be generous. However, the routing of buses around the one-way system (layout 2), which was already oversaturated for part of the peak, caused predicted journey times for all vehicles to increase significantly and the contra-flow lane therefore benefitted both priority and non-priority vehicles.

A similar effect was predicted at site 25, while at site 24, which was operating below capacity, the addition of a low bus flow to the non-priority traffic did not affect predicted journey times.

TABLE 8.1 : AVERAGE JOURNEY TIMES FOR NON-PRIORITY VEHICLES: MEASURED AND PREDICTED USING MAXIMUM THEORETICAL SATURATION FLOWS

SITE NO.	PEAK (P)/ OFF PEAK (OP)	SURVEY NO.	AVERAGE JOURNEY TIME (SECS/VEH)				DIFFERENCE** (SECS/VEH)		
			MEASURED	CONTRAM	TRAFFICQ*	BLAMP	CONTRAM	TRAFFICQ*	BLAMP
1	P	1	26	44	40	35	18	14	9
1	P	2	28	45	44	34	17	16	6
1	OP	1	22	36	37		14	15	
1	OP	2	19	39	39		20	20	
2	P	1	42	21	32		-21	-10	
2	OP	2	43	22	63		-21	20	
2	OP	1	32	19	26		-13	-6	
2	P	2	30	19	25		-11	-5	
3	P	1	31	34	37	38	3	6	7
3	P	2	37	38	38	40	1	1	3
4	P	1	155	52	NF		-103	N/A	
4	P	2	103	53	NF		-50	N/A	
4	OP	1	66	42	70		-24	4	
4	OP	2	78	45	219		-33	141	
5	P	1	69	34	103		-35	34	
5	P	2	74	34	77		-40	3	
5	OP	1	35	31	38		-4	3	
5	OP	2	36	31	38		-5	2	
6	P	1	174	43	52		-131	-122	
6	P	2	140	50	61		-90	-79	
6	OP	1	70	57	87		13	17	
6	OP	2	70	55	93		15	23	
7	P	1	242	82	62		-160	-180	
7	P	2	255	85	66		-170	-189	
7	OP	1	124	85	65		-39	-59	
7	OP	2	130	85	66		-45	-64	
8	P	1	66	27	34		-39	-32	
8	P	2	60	29	34		-31	-26	
9	P	1	180	39	51		-141	-129	
9	P	2	152	39	52		-113	-100	
10	P	1	65	72	81	66	7	16	-1
10	P	2	67	72	88	66	5	21	+1
10	OP	1	55	63	74		8	19	
10	OP	2	53	62	78		9	25	
11	OP	1	47	67	73		20	26	
11	P	2	48	73	71		25	23	
12	P	1	73	39	42		-34	-31	
12	P	2	80	37	42		-43	-38	
12	OP	1	39	34	40		-5	1	
12	OP	2	36	34	40		-2	4	

TABLE 8.1 : (Continued)

SITE NO.	PEAK (P)/ OFF PEAK (OP)	SURVEY NO.	AVERAGE JOURNEY TIME (SECS/VEH)				DIFFERENCE** (SECS/VEH)		
			MEASURED	CONTRAM	TRAFFICQ*	BLAMP	CONTRAM	TRAFFICQ*	BLAMP
13	P	1	55	36	35		-19	-20	
13	P	2	52	32	36		-20	-16	
14	P	1	102	64	403		-38	301	
14	P	2	99	58	419		-41	320	
15	P	1	83	87	107		4	24	
15	P	2	60	67	117		7	57	
15	OP	1	47	47	67		0	20	
15	OP	2	42	48	61		6	19	
16	P	1	182	100	116	91	-82	-66	-91
16	P	2	162	115	222	93	-47	60	-69
17	P	1	127	133	349		6	222	
17	P	2	109	249	266		140	157	
18	P	1	78	82	127	42	4	49	-36
18	P	2	75	84	168	42	9	93	-33
19	P	1	37	46	48		9	11	
19	P	2	40	46	49		6	9	
20	P	1	82	108	135		26	53	
20	P	2	75	108	135		33	60	
21	P	1	27	26	32		-1	5	
21	P	2	31	26	32		-5	1	
22	P	1	49	39	44		-10	-5	
22	P	2	46	39	44		-7	-2	
23	P	1	22	27	35		5	13	
23	P	2	22	27	34		5	12	
24	P	1	101	86	93		-15	-8	
24	P	2	82	86	96		4	14	
24	OP	1	103	85	92		-18	-11	
25	P	1	338	641	nm		303	nm	
25	P	2	251	641	nm		390	nm	
25	OP	1	217	155	nm		-62	nm	
25	OP	2	187	155	nm		-32	nm	

* NF = network full (simulation terminated early)
nm = not modelled

** difference = predicted journey time - measured journey time

TABLE 8.2 : SATURATION FLOW ADJUSTMENTS FOR MODEL CALIBRATION

SITE NO.*	PEAK (P)/ OFF PEAK (OP)	SURVEY NO.	PREDICTED MAXIMUM SATURATION FLOW (PCU/HR)	CHANGE IN SATURATION FLOW TO CALIBRATE (%)			COMMENTS
				CONTRAM	TRAFFICQ	BLAMP	
1+	P	1	2350	46		30	Linked signals
1+	P	2	2350	46		30	Linked signals
1+	OP	1	2350	0			
1+	OP	2	2350	0			
2	P	1	2424	-46			Setback little used
2	P	2	2424	-40			Setback little used
2	OP	1	2424	-58			Setback little used
2	OP	2	2424	-58			Setback little used
3	P	1	1837	0	0	10	
3	P	2	1837	0	0	10	
4	P	1	2485	-14	15		Setback little used
4	P	2	2485	-14	15		Setback little used
4	OP	1	2485	-36	0		Setback little used
4	OP	2	2485	-22	0		Setback little used
5	P	1	1825	-25	12		
5	P	2	1825	-33	12		
5	OP	1	1825	0			
5	OP	2	1825	0			
6∇	P	1	2384	-29	-29		Exit blocking
6∇	P	2	2384	-24	-32		Exit blocking
6∇	OP	1	2384	-4			
6∇	OP	2	2384	0			
7	P	1	1827	-40	-22		Exit blocking/VA signals
7	P	2	1827	-35	-18		Exit blocking/VA signals
7	OP	1	1827	-38			
7	OP	2	1827	-38			
8	P	1	2880	-27	-30		Exit blocking
8	P	2	2880	-20	-30		Exit blocking
9	P	1	1820	0	0		
9	P	2	1820	0	0		
10∇	P	1	4110	0		0	
10∇	P	2	4110	0		0	
10∇	OP	1	4110	0			
10∇	OP	2	4110	0			
11	P	1	4958	-19			
11	P	2	4958	-19			
12+	P	1	4218	-22	-14		Occasional exit blocking
12+	P	2	4218	-29	-14		
12+	OP	1	4218	-16			
12+	OP	2	4218	0			

TABLE 8.2 : (Continued)

SITE NO.*	PEAK (P)/ OFF PEAK (OP)	SURVEY NO.	PREDICTED MAXIMUM SATURATION FLOW (PCU/HR)	CHANGE IN SATURATION FLOW TO CALIBRATE (%)			COMMENTS
				CONTRAM	TRAFFICQ	BLAMP	
13	P	1	4461	-35	-25		Blocking (cross traffic)
13	P	2	4461	-29	-25		Blocking (cross traffic)
14	P	1	1616	-9	20		
14	P	2	1616	-9	22		
15*	P	1	3600	0			
15*	P	2	3600	0			
15*	OP	1	3600	0			
15*	OP	2	3600	0			
16	P	1	3970	-12	-1	-15	
16	P	2	3970	-5	1	-4	
17	P	1	3627	0	16		
17	P	2	3627	14	26		
18	P	1	3903	0	6	-8	
18	P	2	3903	0	6	-5	
19	P	1	3796	28	0		
19	P	2	3796	0	0		
20	P	1	6025	-12	-2		
20	P	2	6025	-12	-2		
21	P	1	4120	0			
21	P	2	4120	0			
22	P	1	2479	-11			
22	P	2	2479	0			
23	P	1	1958	0			
23	P	2	1958	0			
24*	P	1	2550	0			
24*	P	2	2550	0			
24*	OP	1	2550	0			
25*	P	1	3650	-6			
25*	P	2	3650	0			
25*	OP	1	3650	0			
25*	OP	2	3650	0			

Sites marked * are contra-flow sites - saturation flow adjusted at signals at downstream end of bus lane (for non-priority traffic)
Sites marked ∇ have exclusive right turn only lane which is excluded from this analysis
Sites marked + have exclusive left turn only lane - stop line saturation flow then calculated as described in Section 7.1.1.

TABLE 8.3 : EFFECT OF BUS LANES ON JUNCTION CAPACITY: ASSUMPTIONS

SITE NO.*	ENTRY LAYOUT**	DOES BUS LANE REDUCE ENTRY CAPACITY?***	REASON/COMMENTS**
1	3	Yes	Restricted lane use
2	8	Yes	Short setback at roundabout. Packing factor+
3	2	No	Offside lane queue less than setback distance
4∇	8	Yes	Short setback at roundabout. Packing factor+
5	8	No	Existing flare at roundabout controls capacity
6	1,4	No	Exit constriction
7	5	No	Single lane queue at junction
8	2	No	Exit constriction
9	8	No	Exit blocking
10∇	4,6	Yes	No setback
11	4,6	Yes	No setback
12∇	3	No	Exit blocking
13	3	No	Exit blocking
14	8	Yes	Short setback at roundabout. Packing factor+
16	1	No	Adequate setback
17	2,7	Yes	Short setback
18	1,4	Yes	Short setback. Packing factor+
19	3	No	Queueing behaviour unaffected
20	7	Yes	Adequate setback but pelicans restrict capacity
21	6	Yes	No setback
22	7	Yes	Short setback
23	1	Yes	Short setback. Packing factor+

* The 'without' bus lane situation assumes no change in link geometry. Bus lanes at sites marked ∇ involved the provision of an extra lane - this alternative 'without' situation is discussed in Section 7.4

** See Appendix D. For sites marked + see Table 8.3

*** Excludes the effects of intermediate pelican signals within links (Site nos. 4, 9, 10, 11, 18, 19, 20, 12).

Note: These decisions/comments are based on conditions observed at the time of the surveys (e.g. queueing behaviour, signal timings, etc.)

TABLE 8.4 : PREDICTED EFFECTS OF BUS LANE ON VEHICLE JOURNEY TIMES USING CONTRAM

SITE NO.[1]	PEAK (P)/ OFF-PEAK (OP)	SURVEY NO.	AVERAGE JOURNEY TIMES (SECS/VEH)				PREDICTED ADVANTAGE[5] (SECS) TO:	
			WITH BUS LANE			WITHOUT BUS LANE[4]	NON-PRIORITY VEHICLES[6]	PRIORITY VEHICLES
			NON-PRIORITY VEHICLES[2]	PRIORITY VEHICLES				
				MEASURED[3]	PREDICTED			
1	P	1	27	16	24	25	-2	1
1	P	2	28	23	25	26	-2	1
1	OP	1	22	17	22	22	0	0
1	OP	2	18	14	18	18	0	0
2	P	1	42	25	25	33	-9	8
2	P	2	44	30	26	33	-11	7
2	OP	1	32	28	23	32	0	0
2	OP	2	30	32	23	30	0	0
3	P	1	31	41	31	31	0	0
3	P	2	37	39	37	37	0	0
3	P	3	40	35	40	40	0	0
3	P	4	31	30	31	31	0	0
3	P	5	36	33	36	36	0	0
4∇	P	1	155	61	41	55	-100	14
4∇	P	2	103	68	41	55	-48	14
4∇	OP	1	66	58	42	50	-16+	8
4∇	OP	2	78	55	41	48	-30+	7
5	P	1	69	51	69	69	0	0
5	P	2	74	35	74	74	0	0
5	OP	1	34	40	34	34	0	0
5	OP	2	36	33	36	36	0	0
6	P	1	174	89	57	174	0	117
6	P	2	140	73	58	140	0	82
6	OP	1	70	54	57	70	0	13
6	OP	2	70	70	52	70	0	18
7	P	1	242	145	165	242	0	77
7	P	2	255	203	174	255	0	81
7	OP	1	124	98	124	124	0	0
7	OP	2	129	114	129	129	0	0
8	P	1	66	41	34	66	0	32
8	P	2	60	35	29	60	0	31
9	P	1	143	66	46	143	0	97
9	P	2	113	51	47	113	0	98
10∇	P	1	65	41	35	51	-14	16
10∇	P	2	66	40	35	54	-12	19
10∇	OP	1	55	43	35	53	-2	18
10∇	OP	2	53	48	35	52	-1	17

TABLE 8.4 : (Continued)

SITE NO.[1]	PEAK (P)/ OFF-PEAK (OP)	SURVEY NO.	AVERAGE JOURNEY TIMES (SECS/VEH)				PREDICTED ADVANTAGE[5] (SECS) TO:	
			WITH BUS LANE			WITHOUT BUS LANE[4]	NON-PRIORITY VEHICLES[6]	PRIORITY VEHICLES
			NON-PRIORITY VEHICLES[2]	PRIORITY VEHICLES				
				MEASURED[3]	PREDICTED			
11	P	1	47	42	40	44	-3	4
11	P	2	48	51	40	43	-5	3
12∇	P	1	73	52	35	73	0	38
12∇	P	2	80	60	36	80	0	44
12∇	OP	1	39	50	33	39	0	6
12∇	OP	2	36	47	30	36	0	6
13	P	1	55	55	40	55	0	15
13	P	2	52	48	40	52	0	12
14	P	1	102	72	70	78	-24	8
14	P	2	99	65	70	78	-21	8
15+	P	1	83	47	44	83	0	39
15+	P	2	60	45	44	60	0	16
15+	OP	1	47	62	44	47	0	3
15+	OP	2	42	60	44	42	0	-2
16	P	1	182	93	158	182	0	24
16	P	2	162	94	146	162	0	16
17	P	1	127	97	78	78	-49+	0
17	P	2	109	98	109	109	0	0
18	P	1	78	55	34	45	-33	11
18	P	2	75	56	34	45	-30	11
19	P	1	36	45	36	36	0	0
19	P	2	39	50	39	39	0	0
20	P	1	82	55	62	70	-12	8
20	P	2	75	60	62	66	-9	4
21	P	1	27	44	26	26	-1	0
21	P	2	31	35	26	30	-1∇	0
22	P	1	49	48	31	31	-18∇	0
22	P	2	46	40	31	31	-15∇	0
23	P	1	22	26	18	19	-3+	1
23	P	2	22	27	18	19	-3+	1
24+	P	1	101	23	41	59	-42	18
24+	P	2	82	36	38	52	-30	14
24+	OP	1	103	42	41	44	-59	3

TABLE 8.4 : (Continued)

SITE NO.[1]	PEAK (P)/ OFF-PEAK(OP)	SURVEY NO.	AVERAGE JOURNEY TIMES (SECS/VEH)				PREDICTED ADVANTAGE[5] (SECS) TO:	
			WITH BUS LANE			WITHOUT BUS LANE[4]	NON-PRIORITY VEHICLES[6]	PRIORITY VEHICLES
			NON-PRIORITY VEHICLES[2]	PRIORITY VEHICLES				
				MEASURED[3]	PREDICTED			
25^{+}	P	1	338	142	111	164	-174	53
25^{+}	P	2	251	137	111	164	-87	53
25^{+}	OP	1	217	164	108	133	-84	25
25^{+}	OP	2	187	136	108	133	-54	25

1. Sites marked $^{\nabla}$ have additional 'with' bus lane alternatives - see Section 7.4
   Sites marked $^{+}$ are contra-flow bus lanes. The without bus lane alternatives are discussed in Section 7.4.
2. As measured.
3. Excluding time spent at bus stops and associated estimated acceleration/deceleration effects.
4. See Section 8.4.1.2 for without bus lane assumptions at each site.
5. These exclude the small disbenefit to non-priority vehicles which occurs through being 'overtaken' by priority vehicles rather than through capacity reduction.
6. Results unrealistic if disbenefit to non-priority vehicles but NO benefit to priority vehicles (see Section 8.4.1.2). Such sites are marked $^{\nabla}$ and any other sites where this occurs for any interval within the modelled period are marked $^{+}$.

TABLE 8.5 : PREDICTED EFFECTS OF BUS LANE ON VEHICLE JOURNEY TIMES USING TRAFFICQ

SITE NO.[1]	PEAK (P)/ OFF-PEAK(OP)	SURVEY NO.	AVERAGE JOURNEY TIMES (SECS/VEH)				PREDICTED ADVANTAGE[5] (SECS) TO:	
			WITH BUS LANE			WITHOUT BUS LANE[4]	NON-PRIORITY VEHICLES[6]	PRIORITY VEHICLES
			NON-PRIORITY VEHICLES[2]	PRIORITY VEHICLES				
				MEASURED[3]	PREDICTED			
3	P	1	31	41	31	31	0	0
3	P	2	37	39	34	37	0	3
3	P	3	40	35	35	40	0	5
3	P	4	31	30	31	31	0	0
3	P	5	36	33	34	36	0	2
4∇	P	1	155	61	60	78	-77	18
4∇	P	2	103	68	55	61	-42+	6
4∇	OP	2	78	55	56	64	-14+	8
5	P	2	74	35	67	90	16	23
6	P	1	174	89	83	174	0	91
6	P	2	140	73	76	140	0	64
6	OP	1	70	54	70	70	0	0
6	OP	2	70	70	70	70	0	0
7	P	1	242	145	136	242	0	106
7	P	2	255	203	128	255	0	127
8	P	1	66	41	47	66	0	19
8	P	2	60	35	47	60	0	13
9	P	1	180	66	56	180	0	124
9	P	2	152	51	56	152	0	96
12∇	P	1	73	52	40	73	0	33
12∇	P	2	80	60	40	80	0	40
13	P	1	55	55	28	55	0	27
13	P	2	52	48	28	52	0	24
14	P	1	102	72	48	58	-44∇	10
14	P	2	99	65	46	56	-43∇	10
16	P	1	182	93	156	182	0	26
16	P	2	162	94	144	162	0	18
17	P	1	127	97	77	77	-50∇	0
17	P	2	109	98	78	96	-13	18
18	P	1	78	55	47	51	-37	4
18	P	2	75	56	47	51	-34	4

TABLE 8.5 : (Continued)

SITE NO.[1]	PEAK (P)/ OFF-PEAK(OP)	SURVEY NO.	AVERAGE JOURNEY TIMES (SECS/VEH)				PREDICTED ADVANTAGE[5] (SECS) TO:	
			WITH BUS LANE			WITHOUT BUS LANE[4]	NON-PRIORITY VEHICLES[6]	PRIORITY VEHICLES
			NON-PRIORITY VEHICLES[2]	PRIORITY VEHICLES				
				MEASURED[3]	PREDICTED			
19	P	1	37	45	37	37	0	0
19	P	2	40	50	40	40	0	0
20	P	1	82	55	55	65	-17	10
20	P	2	75	60	55	60	-15	5

1. Sites marked ∇ have additional 'with' bus lane alternatives - see Section 7.4
Sites marked + are contra-flow bus lanes. The without bus lane alternatives are discussed in Section 7.4.
2. As measured.
3. Excluding time spent at bus stops and associated estimated acceleration/deceleration effects.
4. See Section 8.4.1.2 for 'without' bus lane assumptions at each site.
5. These exclude the small disbenefit to non-priority vehicles which occurs through being 'overtaken' by priority vehicles rather than through capacity reduction.
6. Results unrealistic if disbenefit to non-priority vehicles but no benefit to priority vehicles (see Section 8.4.1.2). Such sites are marked ∇ and any other sites where this occurs for any interval within the modelled period are marked +. See Section 8.4.1.2 for further explanation.

TABLE 8.6 : PREDICTED EFFECTS OF BUS LANE ON VEHICLE JOURNEY TIMES USING BLAMP

SITE NO.[1]	PEAK (P)/ OFF-PEAK(OP)	SURVEY NO.	AVERAGE JOURNEY TIMES (SECS/VEH)				PREDICTED ADVANTAGE (SECS) TO:	
			WITH BUS LANE			WITHOUT BUS LANE[4]	NON-PRIORITY VEHICLES	PRIORITY VEHICLES
			NON-PRIORITY VEHICLES[2]	PRIORITY VEHICLES				
				MEASURED[3]	PREDICTED			
1	P	1	27	16	18	24	-3	6
1	P	2	28	23	20	26	-2	6
3	P	1	31	41	23	26	-4	3
3	P	2	37	39	31	33	-4	2
10[∇]	P	1	65	41	35	51	-14	16
10[∇]	P	2	66	40	35	52	-14	16
14	P	1	102	72	82	102	0	20
14	P	2	99	65	79	88	-11	9
16	P	1	182	93	169	182	0	13
16	P	2	162	94	158	162	0	4
18	P	1	78	55	36	45	-33	9
18	P	2	75	56	36	45	-30	9

1. Sites marked ∇ have additional 'with' bus lane alternatives - see Section 7.4.
2. As measured.
3. Excluding time spent at bus stops and associated estimated acceleration/deceleration effects.
4. See Section 8.4.1.2 for without bus lane assumptions at each site.

TABLE 8.7 : QUEUE LENGTH PREDICTIONS BY MODELS FOR SELECTED SITES[1]

SITE NO.	PEAK SURVEY	BUS LANE LENGTH, L[2] (m)	% OF SURVEY THAT QUEUE ≥ L FROM			MAXIMUM QUEUE (m) PREDICTED BY:		
			OBSERVATION[3]	CONTRAM	TRAFFICQ	CONTRAM	TRAFFICQ[4] 1	TRAFFICQ[4] 2
6	1	200	60	12	30	200	280	320
6	2	200	50	0	30	160	262	291
7	1	1109	30	0	0	517	638	727
7	2	1109	30	0	0	396	585	601
8	1	144	80	67	60	353	573	600
8	2	144	70	67	70	320	491	515
9	1	366	20	0	30	209	429	456
9	2	366	10	0	0	176	347	371

1 Those where queue lengths were observed to exceed the bus lane length for part of a survey.
2 Including setback.
3 These are subjective estimates.
4 TRAFFICQ 1 : Taken from average queue length information (for comparison with CONTRAM).
2 : Taken from detailed queue length distribution.

TABLE 8.8 : MEASURED AND PREDICTED AVERAGE SPEEDS FOR PRIORITY VEHICLES

SITE NO.[1]	MEASURED AVERAGE SPEED (kph)		AVERAGE 'CRUISE' SPEEDS (kph) EXCLUDING JUNCTION EFFECTS			DIFFERENCE IN CRUISE SPEEDS[7] (%)	FEATURES OF SITE[8]
	OVERALL[2]	LESS STOPS[3]	MEASURED FOR MODEL INPUT[4]	INFERRED FROM MODEL			
				LESS STOPS[5]	INCLUDING STOPS[6]		
1	35	35	43	48	48	12	a
2	17	26	43	53	26	23	
3	11	18	43	40	17	-7	b
4	23	26	43	27	24	-37	
5	14	28	43	43	30	0	
6	9	9	32	16	16	-50	a,c,d,e
7	19	24	54	51	36	-6	d,e
8	9	14	43	29	13	-33	a,b,d,e
9	19	23	43	26	22	-40	
10	21	33	43	34	21	-21	
11	16	28	43	36	19	-16	c
12	25	28	54	37	33	-31	f
13	14	14	43	27	27	-37	a
14	19	21	43	30	26	-30	c
15∇	13	13	36	32	32	-11	a,c
16	26	34	61	61	40	0	
17	27	27	54	54	45	0	
18	31	34	61	44	40	-28	f
19	21	31	61	45	26	-26	
20	21	33	47	58	30	23	
21	12	20	58	29	15	-50	c
22	13	20	43	43	23	0	
23	11	26	43	32	12	26	a,b
24∇	2	8	36	36	2	0	a,b
25∇	15	23	43	31	18	-28	
AVERAGE	18	24	46	38	26	-17	

1 Sites marked ∇ are contra-flow bus lanes
2 Includes time spent at bus stops and junction delays
3 Excludes time spent at bus stops but includes junction delays
4 These are as measured for non-priority vehicles
5 These are calculated such that overall predicted journey time equals that observed
6 As 5 but including stops
7 Difference = [(col5 - col4) x 100/col4]%
8
- a Short bus lane length, taken as < 200m
- b High bus stop frequency, taken as > 6 bus stop stations per km of bus lane
- c High degree of illegal use of bus lane. One or more vehicles stopped in lane for a 'significant' period (taken as > 30% of survey)
- d Queue of non-priority traffic adjacent to the bus lane exceeding the bus lane length for part of the survey period
- e High pedal cycle flows, taken as > 100 per hour
- f Uphill gradient, taken as > 5%

TABLE 8.9 : RESULTS OF MODELLING ALTERNATIVE 'WITHOUT' BUS LANE SITUATIONS

SITE NO.	SURVEY NO.	ALTERNATIVE LAYOUT	AVERAGE JOURNEY TIME (SECS/VEH) WITH BUS LANE: NON-PRIORITY VEHICLES	AVERAGE JOURNEY TIME (SECS/VEH) WITH BUS LANE: PRIORITY VEHICLES	WITHOUT BUS LANE	PREDICTED BENEFITS (SECS) TO: NON-PRIORITY VEHICLES	PREDICTED BENEFITS (SECS) TO: PRIORITY VEHICLES
4	1	1	155	41	55	-100	14
4	1	2	155	41	848	693	807
10	1	1	65	35	51	-14	16
10	1	2	65	35	77	12	42
12	1	1	73	35	35	-38	0
12	1	2	73	35	245	172	210
15$^{\nabla}$	1	1	63	44	63	0	19
15$^{\nabla}$	1	2	63	44	96	33	52
24$^{\nabla}$	1	1	101	41	59	-42	18
24$^{\nabla}$	1	2	101	41	101	0	60
25$^{\nabla}$	1	1	338	111	164	-174	53
25$^{\nabla}$	1	2	338	111	418	80	307

1. Sites marked $^{\nabla}$ are contra-flow bus lanes
2. Alternative 1 involves removal of bus lane and route restrictions

   Alternative 2 for with-flow lanes involves removal of bus lane and reduction in link width by 1 lanes

   Alternative 2 for contra-flow lanes involves the routeing of buses around the one-way systems (i.e. via the non-priority traffic routes)

FIGURE 8.1 : EXAMPLE OF SENSITIVITY OF DELAY TO TRAFFIC INTENSITY FOR TRAFFICQ, CONTRAM AND BLAMP

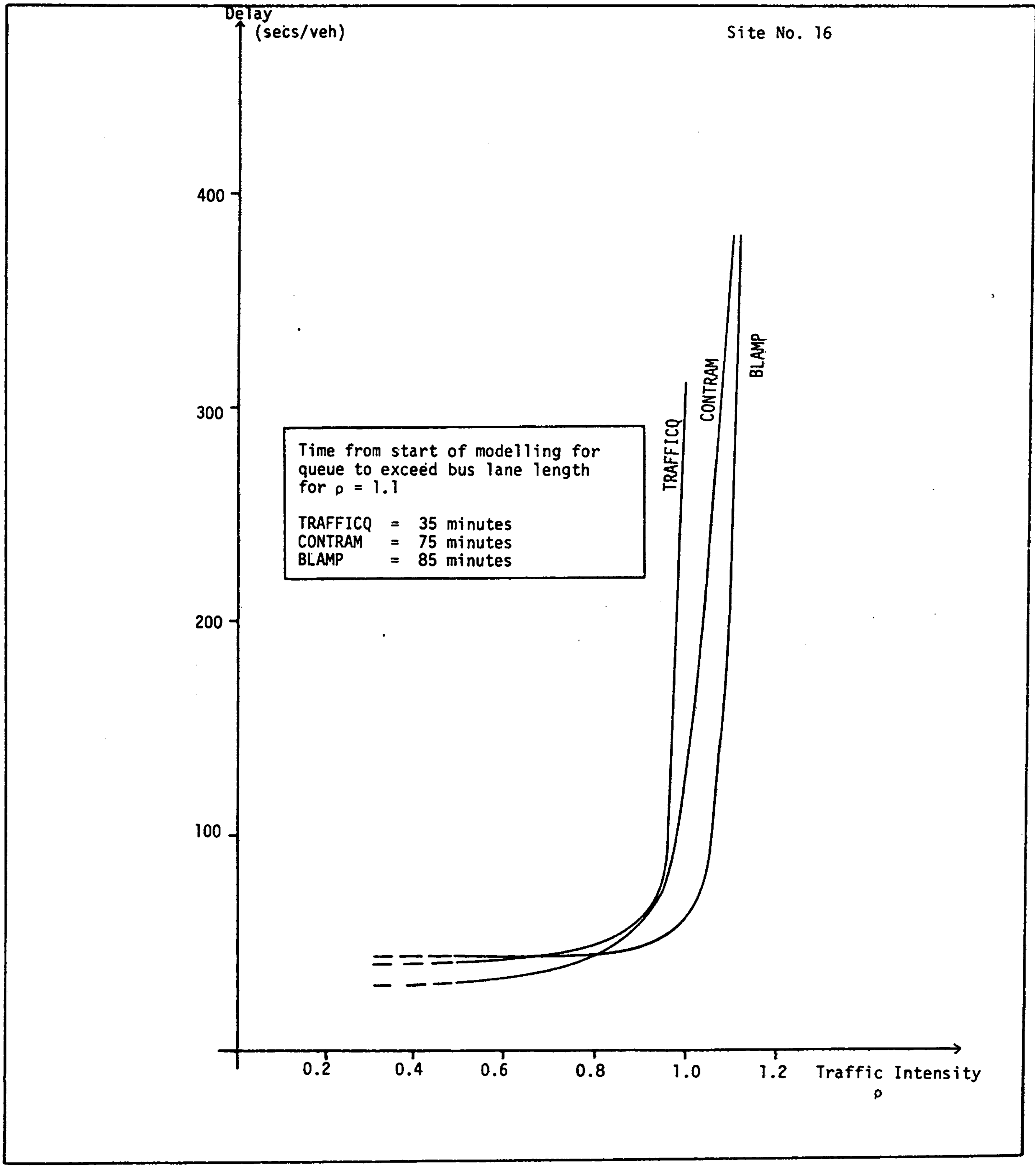


FIGURE 8.2 :AVERAGE MEASURED JOURNEY TIME FOR NON PRIORITY VEHICLES AGAINST THOSE PREDICTED BY TRAFFICQ, USING MAXIMUM THEORETICAL SATURATION FLOWS.

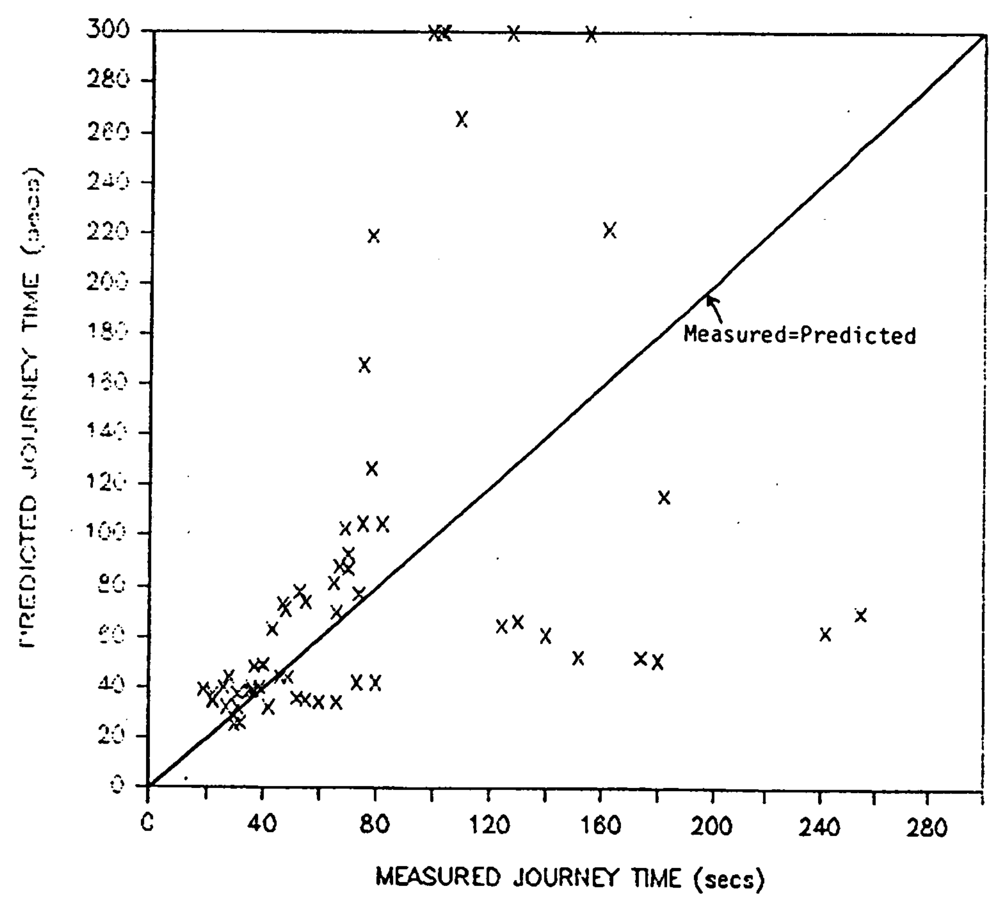


FIGURE 8.3 :AVERAGE MEASURED JOURNEY TIMES FOR NON PRIORITY VEHICLES AGAINST THOSE PREDICTED BY CONTRAM,USING MAXIMUM THEORETICAL SATURATION FLOWS.

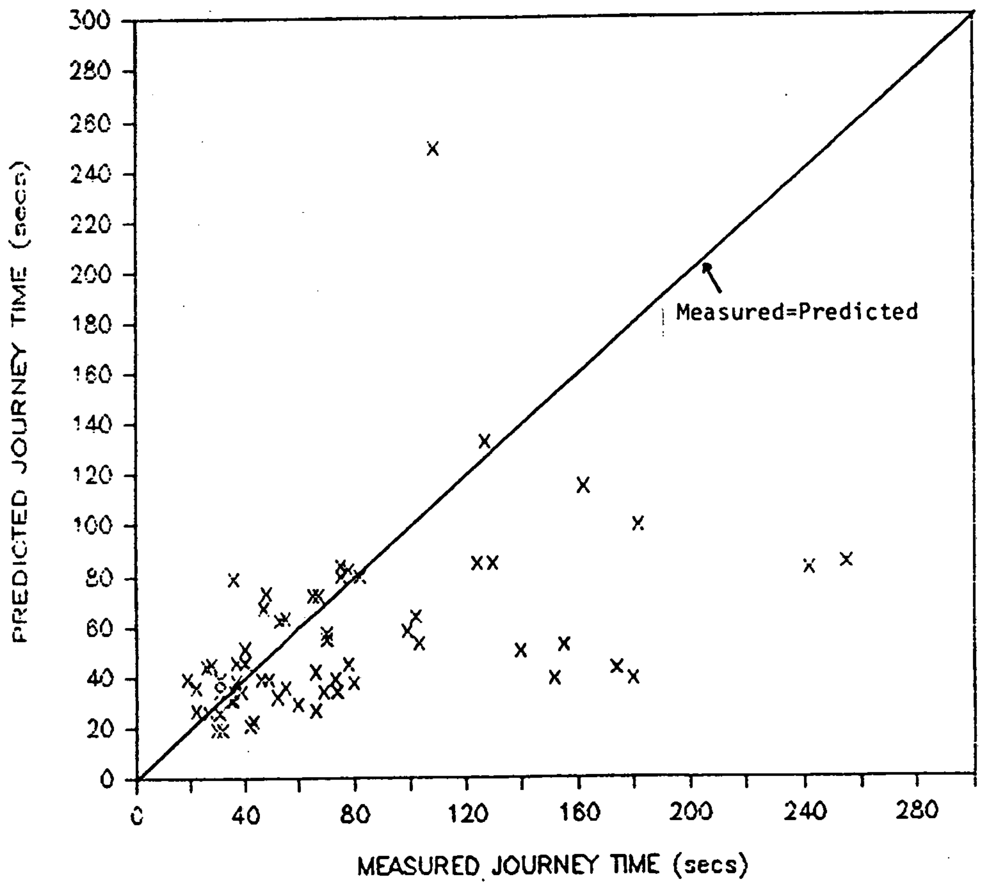


FIGURE 8.4 :COMPARISON OF AVERAGE MEASURED JOURNEY TIME WITH THOSE PREDICTED BY TRAFFICQ, CONTRAM AND BLAMP AT A SAMPLE OF SITES USING MAXIMUM THEORETICAL SATURATION FLOWS.

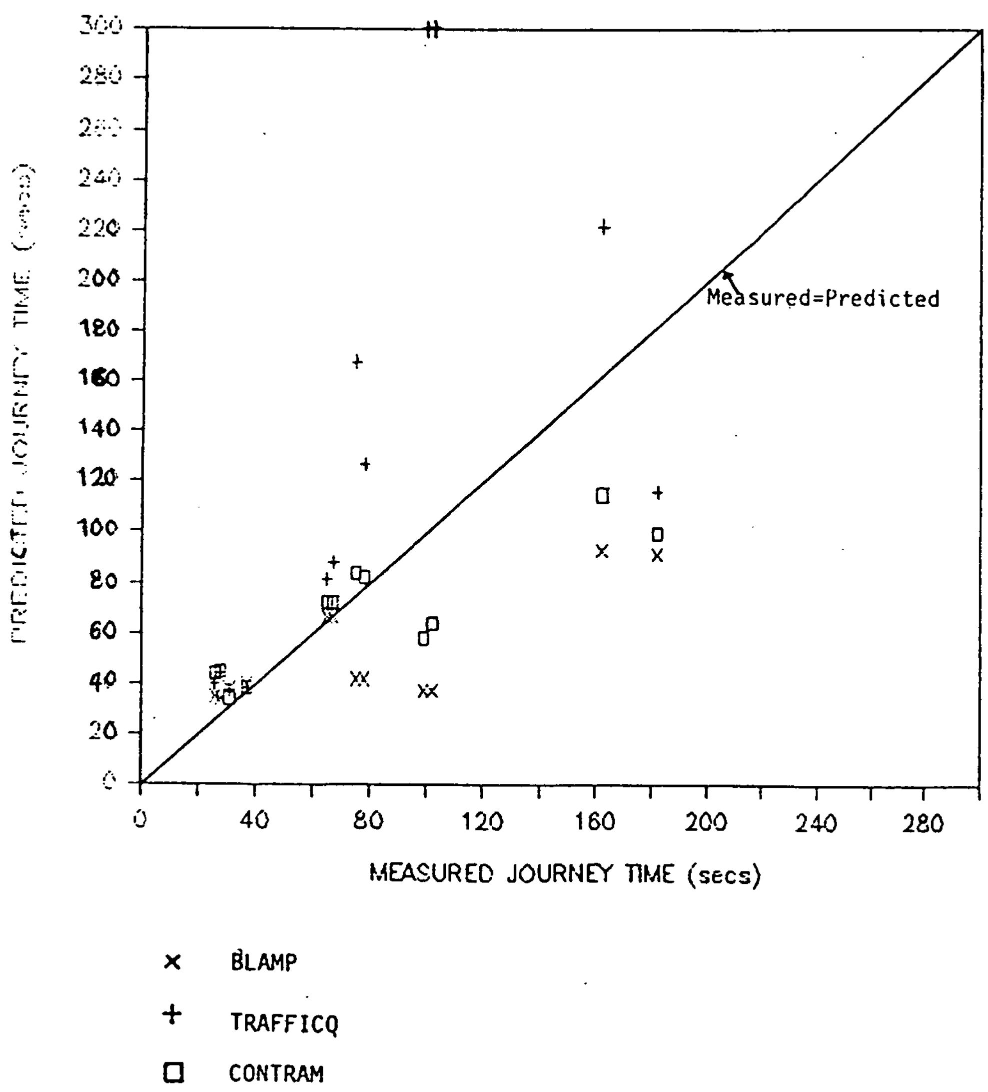
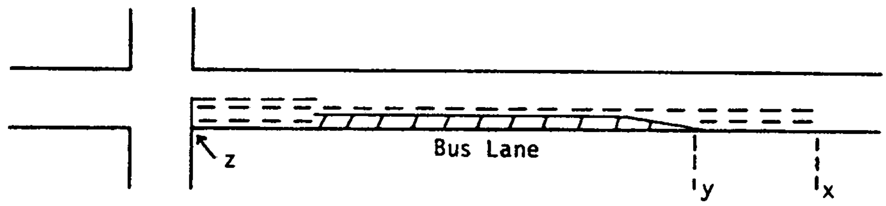
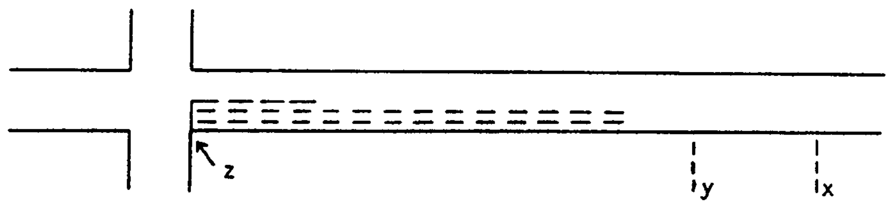


FIGURE 8.5 : EXAMPLE OF JOURNEY TIME COMPARISONS WHEN QUEUES EXTEND UPSTREAM OF THE START OF THE BUS LANE

WITH BUS LANE



WITHOUT BUS LANE



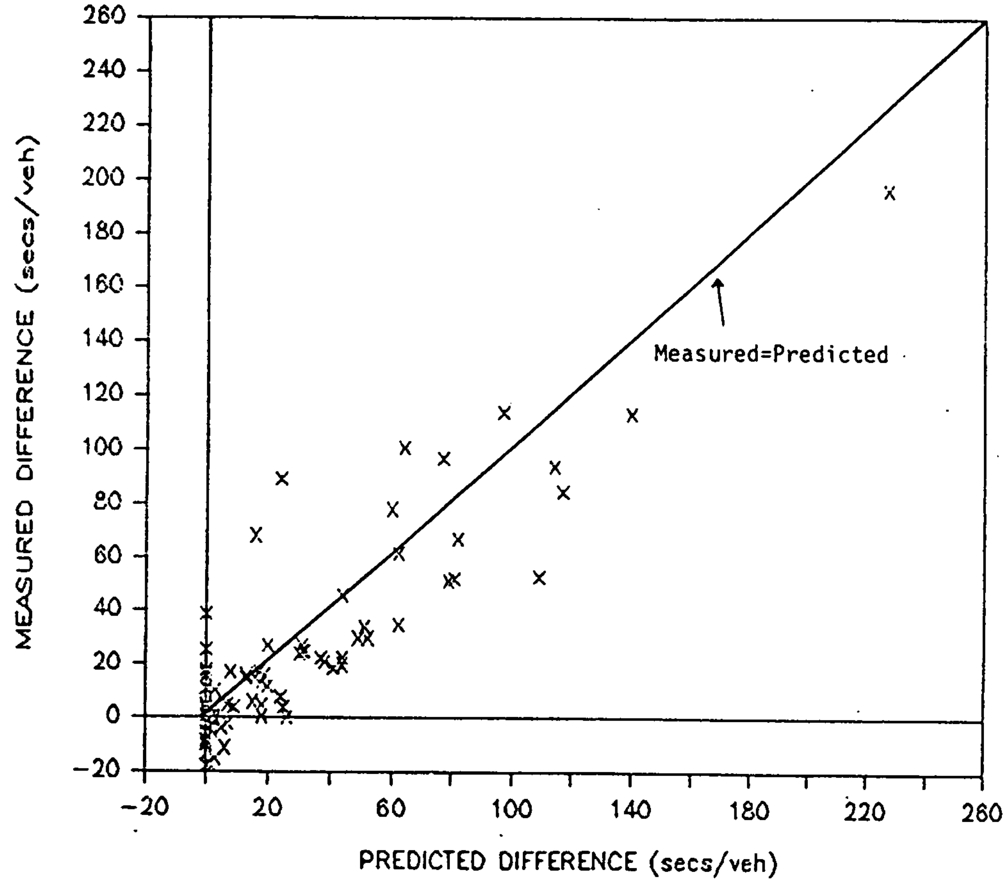
In this example, the number of non-priority vehicles queueing and delay per vehicle are the same with and without the bus lane. However, queue lengths differ due to the bus lane. Typical journey times are given below :

Vehicle Type	Journey Times (secs/veh)					
	Section x to z			Section y to z		
	With bus lane	Without bus lane	Benefit	With bus lane	Without bus lane	Benefit
Priority	100	160	60	40	140	100
Non-Priority	160	160	0	100	140	40

Thus, if journey times were compared with and without the bus lane over the length y-z, the benefit of the bus lane to all vehicles would be overpredicted by the amount of delay over the section x-y (i.e. 40 secs/veh in this example).

Note : These calculations exclude the small disbenefit to non-priority vehicles caused by priority vehicles 'jumping the queue'.

FIGURE 8.6 :COMPARISON OF MEASURED DIFFERENCES IN AVERAGE JOURNEY TIME, BETWEEN NON PRIORITY VEHICLES AND BUSES,WITH THOSE PREDICTED BY CONTRAM.



SECTION NINE

ECONOMIC EVALUATION

9.1 METHOD OF APPROACH

The economic evaluation of a bus lane requires a comparison to be made between the total costs of the bus lane and its predicted/measured benefits. The basis of the evaluation adopted here has been to estimate benefits for the year 1985, rather than to attempt a longer term evaluation based on the expected 'life' of the bus lane (which would be largely uncertain). If it were desired to evaluate the benefits of a bus lane over a longer time horizon estimates of modal split, traffic growth and associated delays would be required over the same period. The evaluation methods adopted have been consistent with standard Department of Transport procedures, as, for example, are contained within the COBA[20] program for the economic evaluation of highway schemes.

9.2 COSTS

The main costs associated with a bus lane are due to its implementation, maintenance and enforcement (excluding the time involved in such items as planning, design and assessment, the costs of which may be significant compared to the usually relatively low cost of implementation). Evidence from the NATO report suggests that implementation costs for with-flow lanes generally lie in the range £2-£15 per metre of bus lane length (1976 report). In their recent study[8] Jamieson Mackay and Partners assumed a cost of £6 per metre for signs and road markings to exclude design, administration, agency fees and any other improvements associated with the bus lane. Costs obtained from Local Authorities in this study ranged from £3 to £6 per metre (1975 prices) although much higher costs were incurred at a number of sites where associated work was involved (see Appendix A : Data Base). For the purposes of this evaluation, a minimum implementation cost of £10 per metre of bus lane has been assumed (1985 prices).

Implementation costs of contra-flow bus lanes are generally considerably higher and more variable than those for with-flow lanes due to the extra works which are involved, particularly concerning new junction layouts which may be required at each end of the bus lane. The NATO[12] report gives costs ranging from £1 to £50 per metre depending on length and complexity while in this study the cost of the one site where relevant figures were known (site 24) was £21 per metre (1975 prices).

Maintenance costs of bus lanes are associated mainly with renewal of road markings and the maintenance of signs. Costs of these items have not generally been available although they are likely to be small.

The costs associated with enforcement of a bus lane, in terms of both parking warden time and police time associated with moving violations are again uncertain and likely to be highly site specific depending on the degree of violations occurring.

Costs associated with removal of a bus lane have not been considered here, but are thought to be of the same order of magnitude as implementation.

9.3 BENEFITS

The main benefit of a bus lane scheme is expected to be related to the journey time savings to occupants of priority vehicles. Other benefits may also arise through savings for bus passengers in walking and/or waiting time and improved reliability while the Operator may also benefit through reduced vehicle operating costs and the attraction of more passengers to the service, yielding an increase in revenue. The main disbenefit of a bus lane arises from the increase that may occur in journey time for occupants of non-priority vehicles and associated increases in vehicle operating costs. The scale of the overall benefit/disbenefit of a scheme is therefore related to the relative flows and number of occupants of priority and non-priority vehicles and the effect of the bus lane on the journey times of occupants in each category of vehicle.

There may also be a benefit/disbenefit of a scheme through changes in accident rates but these are considered to be best assessed through measurement rather than prediction and are excluded here.

9.3.1 Journey Times for Vehicle Occupants

The economic evaluation of the effect of each bus lane studied on journey time changes has been undertaken using two possible approaches. The first covers with-flow sites where the bus lane is considered to have had an insignificant effect on the journey time of non-priority vehicles other than through the overtaking effect of priority vehicles.

Such sites are listed in Table 8.3 and included those where optimum setbacks were provided and used, exit blocking effects predominated or the bottleneck capacity was unaffected by the bus lane (e.g. only a single lane of traffic could be accommodated). The journey time for all vehicles 'without' the bus lane was then calculated using the procedure described in Section 6.2.

The second approach concerned those sites where the bus lane was taken to have reduced the theoretical capacity of the junction at the end of the bus lane, resulting in delays to non-priority vehicles in addition to the overtaking effect. These sites are also listed in Table 6.2. In this situation, the 'without' bus lane journey times assumed were those predicted by CONTRAM, this model having been applied to all the relevant sites. There is evidence to suggest that at some sites this approach results in an overestimate of the disbenefit of the bus lane (see Section 8.3). Where overestimation is known to have occurred economic disbenefits have not been calculated although it should be stressed that disbenefit could have been substantial at these sites. Because of the uncertainty, maximum benefits have also also been calculated at these sites using the approach described above (i.e. as in Section 6.2), although these are not considered likely to have been achieved.

The values of time used in the economic calculations are based on those given in the Highways Economics Notes 2 (HEN2) which are incorporated within COBA[20]. The HEN2 values for 1979 have been factored by 1.63 for inflation to convert them to 1985 values and by 1.05 for real growth as shown in Table 9.1A. (The factor of 1.05 is midway between the high and low growth alternatives given in HEN2). In accordance with HEN2, it has been assumed that 1% of bus passengers and 16.7% of car occupants are travelling in working time. All Other Goods Vehicle (OGV) drivers have been assumed to be travelling in working time.

These figures are based on national average conditions throughout the day, and it was suspected that they may produce a bias in the benefit calculations. Further investigation from the 1978/79 National Travel Survey[25] has shown that this is likely to be the case as illustrated in the figures in Table 9.1B. In particular, it is noted that the ratio of trips in peak periods undertaken during the course of work between car and bus occupants is of the order of 3:1 rather than 16:1 as given in HEN2. Alternative values of time based on these figures have therefore been calculated, as shown in Table 9.1B and the effects of these changes have been assessed at a sample of sites as described later in this section.

The journey time results/predictions for each site normally covered two peak and two off-peak periods (where appropriate). These results, although limited, have been taken to represent all year round effects and average values of traffic flows, journey times and associated factors based on these two days of information have therefore been used in the economic evaluation. There is clearly considerable uncertainty in extending results of observations on two days to give annual benefits/disbenefits as, for example, the effect of the bus lane on a few days in a year when congestion is widespread may be significant and different from that on 'normal' days. In such conditions, a bus lane would probably offer greatest advantage to buses but may significantly disbenefit other traffic due to problems of blocking back arising from the loss in queueing space. Although designing/evaluating for 'average' conditions may not always be the best solution, it has been widely adopted in UK practice and has therefore been adopted here.

Where the surveys were started after the beginning of the operational period of a bus lane, or terminated before the end of it, additional benefits/disbenefits were calculated to cover the periods where data was not available. This was undertaken by assuming that benefits/disbenefits estimated for the survey period reduced linearly to zero at the start and/or end of the operational period. The bus lanes surveyed were generally situated on main radial routes and traffic flows were therefore tidal. Where a bus lane operated for two peak periods per day, it was usual for its effect to be greatest in one of the peaks, benefits in the other 'peak' being generally marginal. Surveys were then restricted to the 'dominant' peak period and benefits/disbenefits were calculated for this period only. In practice, decisions on the evaluation period need to be made on a site-specific basis. For bus lanes operating for 12 hrs per day estimates of off-peak benefits/disbenefits were assumed to apply linearly throughout the working day (i.e. usually between 0930 hrs and 1630 hrs). Bus lanes operating for 24 hours per day were assumed to have no effect outside of the working day (i.e. usually between 1800 hrs and 0730 hrs). This is not strictly correct at the contra-flow sites where distance related benefits/disbenefits applied continuously, and in practice, a more thorough evaluation using appropriate traffic flows (i.e. overnight, at weekends, etc.) would be required. All benefits/disbenefits were calculated assuming 250 working days per year.

The vehicle occupancies used in the analyses are those recorded during the course of the surveys at each site, as given in Table 9.2. (This table also gives details of 'person' flows per hour for priority and non-priority vehicles.) Over all surveys, the average car occupancy recorded was 1.44 which can be compared with HEN2 values of 1.21 for a working car and 1.87 for a non-working car. Measured peak and off-peak car occupancies were not significantly different. The average bus occupancy recorded for all surveys was 27 which is significantly higher than the value of 15.55 given in HEN2. There was also a significant difference between peak and off-peak bus occupancies, average recorded values being 32 and 18 respectively.

The general formula used for calculating the time related costs (C_i) for each vehicle class for each survey (from which an annual estimate was made) was:

$$C_i = T_i \times q_i \, [(O_i \times V_{pi}) + V_{di}] \qquad \text{............ 9.1}$$

Where T_i = average journey time for vehicle of class i
q_i = flow for vehicle of class i
O_i = passenger occupancy for vehicle of class i
V_{pi} = value of time for passengers of vehicle class i
V_{di} = value of time for driver of vehicle class i

These costs were aggregated for all vehicle classes to give the overall journey costs. 'With' and 'without' bus lane journey costs were calculated in a similar manner, using appropriate values of T_i. A more rigorous analysis would have involved similar calculations within smaller time intervals during the peak period to account for variations in bus occupancies and journey times therein. Limited calculations of this nature at the study sites showed these effects to be small however.

9.3.2 Vehicle Operating Costs

Vehicle operating costs (non-fuel) have been calculated from the relationship given in HEN2:

$$\text{Cost (pence/km)} = a + \frac{b}{V} + cV^2 \qquad \text{......... 9.2}$$

Where V = vehicle speed (kph)
a,b,c are constants related to the vehicle type

The values used for a, b and c are those given in HEN2, 1979, factored by 1.63 for inflation as shown in Table 9.1. These values refer to the non fuel element of vehicle operating costs for the different vehicle types. Total vehicle operating costs (non fuel) for each survey were thus obtained by multiplying the results from equation 9.2 for each vehicle class by the volume of traffic in that class and the bus lane length, results then being aggregated for all vehicle classes. The equivalent calculation for the without bus lane situation simply required the average speed (V) to be changed as necessary.

For the urban situation where junction delays are significant it was considered preferable to use fuel consumption relationships relevant to this environment rather than those given in HEN2. Such relationships in which fuel consumption is divided into cruising and delay elements, are used within CONTRAM and are described beneath Table 9.1. Thus, fuel consumption of the different vehicle classes was obtained either directly from CONTRAM or by calculations using the same relationships where relevant predictions were not available. Resource costs of fuel per litre were based on 1985 pump prices, factored to take account of Value Added Tax and duty. The cruising element of fuel consumption was assumed to be the same 'with' and 'without' the bus lane (being related to cruise speed) but the delay element varied according to the measured/predicted delay for each vehicle class 'with' and 'without' the bus lane.

9.3.3 Overall Benefits

The total economic benefits/disbenefits (journey time and vehicle operating costs) calculated for each site are given in Table 9.3. Benefits associated with journey time savings typically comprised around 80% of the total economic benefits. Benefits/disbenefits in Table 9.3 are given for priority and non-priority vehicles separately, as well as for all traffic combined, and are also divided into peak and off-peak periods, again with a total overall figure.

At sites where the measured average journey time for buses (less stops) exceeded that for non-priority vehicles, it has not been possible to calculate a maximum economic benefit and a value of zero is given in Table 9.3. Those sites where the average journey time saving for buses was not statistically significant are also identified in Table 9.3 as are those where predicted disbenefits were unrealistically high (see Section 8.3) but where substantial disbenefits were likely.

The results for sites 4, 10 and 12 in Table 9.3 apply to the comparison of the 'with' and 'without' bus lane situations assuming no change in road geometry. However, these bus lanes were formed by the introduction of an additional lane which has produced significant predicted savings in journey times (as given in Table 8.9, alternative layout 2). There is some uncertainty in these predictions (as discussed in Section 8.5) but even at site 10, the predicted annual economic benefit of the bus lane in evening peak periods alone changes from -£8,400 (Table 9.3) to in excess of £10,000.

The maximum benefits in Table 9.3 for the contra-flow sites were obtained by comparing current conditions with those modelled when buses were restricted to using the circulating routes (i.e. alternative layout 2 in Section 8.5). Considerable benefits were apparent from the bus lanes in this situation. The values of predicted benefit for contra-flow lanes in Table 9.3 are those assuming that the lane currently reserved for buses is made available to all traffic. With this option, large disbenefits were predicted. However, the results for the contra-flow lanes are limited to the effects on traffic which would use the bus lane if permitted - in practice, traffic on adjacent links would also be affected and the overall impact on all traffic would need to be assessed from the model output. Thus, although the results in Table 9.3 illustrate the approximate effects of different options, the absolute values are uncertain.

A feature of the results in Table 9.3 is the variability between the predicted benefits from modelling and the maximum benefits from measurement/calculation. These uncertainties (particularly in the modelling) have led to a limited sensitivity analyses being undertaken at three of the study sites which cover the range of benefits found. In the first of these analyses, 'without' bus lane predictions/ measurements of journey time have been varied by 5 and 10 secs and the effect on overall benefits monitored. The results (which exclude vehicle operating costs) are given in Table 9.4A. The relationship between overall benefits and 'without' bus lane journey times is approximately linear. On average, an error in this journey time prediction of 10 seconds per vehicle was found to cause an error in journey time benefits of around £3,400/annum (i.e. if the journey time is overpredicted by 10 secs, the benefit will be underestimated by around £3,400/annum on average). This is the approximate cost of an 'average' with-flow bus lane and the importance of accurate journey time predictions is therefore clear.

The second set of sensitivity tests involved the use of different values of travel time, as set out in Table 9.1B, which are thought to be more appropriate for assessing the economic benefits of bus lanes, particularly in peak periods (see Section 9.3.1). The results are given in Table 9.4B. For peak periods only, the new values result in a reduction in disbenefit to non-priority traffic of around 20% and an increase in the benefit to priority vehicles of around 5%, making an overall increase in benefit for the bus lane of between 10-15%. The increase in benefit during off-peak periods was only around 2%, as the percentages of journey stages in the course of work were much closer to those given in HEN2 for this period (see Table 9.1B).

9.4 DISCUSSION OF RESULTS

A main feature of the results given in Tables 9.3 and 9.4 is the high level of predicted disbenefit that occurs at a number of the study sites. The sites where this occurs correspond to those where the setback has been predicted to be too short and therefore causing a loss in junction capacity. With most sites operating at around capacity at peak periods this can have a significant effect. This is illustrated in Figure 8.1 where, at high traffic intensities, even small reductions in capacity (which is directly related to traffic intensity) cause considerably increased delays.

Some comments are given below on the predicted economic benefits from the sites, with reasons for their variability. Comments refer to the simple alternative of allowing all traffic to use the bus lane, rather than there being one less lane available for all traffic (as occurred originally at some of the sites). Further comments on operational characteristics existing are given for each site in Appendix A.

Sites 1 *and* 2 form consecutive links within a bus lane system. The small predicted disbenefits at site 1, which generally operated below capacity were due to the restriction of the nearside lane in the setback to left turn only traffic, which is necessary due to the continuing bus lane downstream (Site 2). The larger predicted disbenefits at site 2 were due to the short setback associated with the roundabout entry: It is possible that these disbenefits are overestimated due to the method adopted to calculate entry capacity (see Section 8.4.1). Nevertheless, even the maximum benefits predicted at these sites (£1000 and £1700/annum respectively) are well below city council predictions in 1975 (£1,740 and £5,334/annum respectively, see Appendix A), although traffic and operating conditions have altered in the period. The additional delay to non-priority traffic which is predicted to result from these bus lanes may in reality be offset to some extent by reduced delays at junctions with lower capacities on the eastbound radial downstream. Removal of these bus lanes in isolation is not likely to be worthwhile.

Site 3 generally operated below capacity but offered some benefits to buses during the peak period. Although the setback was less than the predicted optimum, little through traffic used the offside lane which contained opposed right turning traffic. Queueing was therefore predominantly single lane, a situation where a bus lane is well suited.

Large disbenefits were predicted at site 4 due to the short setback approaching the roundabout and the small use made of it. (At worst, these disbenefits were of the order of £100,000/annum). Such predictions were considered to be large overestimates, due to the method of calculating entry capacity (see Section 8.4.1) and the likelihood that full use would not have been made of the flare anyway due to the dominant right turning flow. Although full surveys were only conducted during evening peak periods, subsequent limited observations showed that buses enjoyed similar benefits in morning peak periods. During these periods queues were shorter but circulating traffic was heavier so that delays/queues were comparable. The number of vehicles able to 'gap accept' in these circumstances was much reduced, as would have been any detrimental effect of the short setback. It was not considered that realistic predictions of economic benefits could be given for this site.

Site 5 offered benefits for buses for short periods during peak hours without there being any predicted disbenefit to other traffic. This was because the setback at the roundabout was sufficient and was superimposed on an already existing flare which was more critical in controlling capacity.

Site 6 contained a setback shorter than the predicted optimum but was subject to an exit constriction/blocking which generally controlled congestion on the link. Predicted disbenefit to non-priority traffic due to the bus lane was therefore small, although it could have been somewhat higher in reality, particularly for left turners who experienced little exit blocking but were mixed with through traffic due to the bus lane and for upstream crossing traffic which was frequently blocked. These effects could not be quantified.

Large benefits were predicted at site 7, where long delays were avoided by buses but which were inevitable for non-priority traffic (due to road narrowing) with or without the bus lane. Again, some disbenefits would have occurred to crossing traffic upstream which was frequently blocked, but these were not quantified.

Sites 8 and 9 comprise consecutive bus lane links. Congestion spread from immediately downstream of site 8 (due to exit problems) through both links during the morning peak and significant benefits were gained by buses. The setbacks at sites 8 and 9 were shorter than theoretically recommended, but were not observed to be reducing junction capacity because of the exit blocking conditions. Predicted benefits exclude any disbenefits which may have occurred to crossing traffic or through re-assignment onto local minor roads, which could not be quantified.

The bus lane at site 10 was constructed as a special facility for buses and has no setback as it leads into a contra-flow lane. Extending its use to all traffic would provide significant predicted benefits due to the increase in junction capacity, but would require junction re-design and exit re-alignment. One effect would be to transfer some delays from this link to the next signal controlled link downstream. Removal of the facility is not therefore likely to be worthwhile overall.

Sites 11 and 13 are consecutive bus lane links. Predicted disbenefits at site 11 were due to the loss in capacity at the signal controlled junction, where no setback was provided as there was no left turning movement and the bus lane continued downstream. Smaller disbenefits also occurred at the pelican crossing within the link for similar reasons. Delay on link 13 is predicted to be due more to crossing traffic at the downstream junction and to exit problems rather than to the bus lane on the link itself, although this is uncertain. Predicted benefits may therefore be higher than in reality. Little use is made by buses of these bus lanes, due partly to parking violations, and their usefulness is doubtful.

Site 12 has high predicted peak benefits as it was not predicted that junction capacity would be increased through removal of the bus lane on the link. However, this may not be the case if the short bus facility downstream was also removed and the benefits may therefore be overestimated to some extent.

The large disbenefits predicted for site 14 are associated with the loss in theoretical junction capacity due to the short setback at the roundabout entry. As at site 4, these disbenefits may be overestimates (see Section 8.4.1) possibly exacerbated by the dominant right turning movement which may have resulted in less use of the nearside lane than 'normal' even without a bus lane operating.

The benefits at *site* 15 (a contra-flow bus lane) relate to two alternative modes of operation as discussed in Section 9.3.3.

Site 16 has high predicted benefits: The setback was sufficient not to reduce junction capacity and buses were able to avoid substantial queues that built up during parts of the peak period.

Variation in signal timings at *site* 17 recorded between two days of surveys had a significant effect on predicted benefits between days. (Signal timings matched the flared (and setback) length on one day but not on the other.) It was not therefore considered that realistic annual predictions could be given. The signal entry is highly flared and appropriate signal timings were clearly essential for operational efficiency.

The high predicted disbenefits at *site* 18 were due to the link having a (necessary) high proportion of green time (0.83). The setback was considerably shorter than recommended in H6/76, but was (correctly) related to the short red time (i.e. the setback should not be too long that it cannot be refilled once per cycle). Few vehicles used the short setback, however. The introduction of a bus lane on a link where the proportion of green time (λ) is high (i.e. $\lambda > \sim 0.6$) inevitably leads to a loss of junction capacity.

Queues on the survey days at *site* 19 did not significantly exceed the setback distance, and no benefits/disbenefits of the bus lane were therefore predicted.

The predicted disbenefits at *site* 20 were due mainly to the pelican crossings on the link, which had a theoretically reduced capacity of some 50% in the 'with' bus lane situation. This loss may not have occurred in reality if parking was widespread before the bus lane was introduced. The setback at the signal controlled junction was sufficient not to cause any loss in capacity for the prevailing signal timings.

Site 21 forms an internal section of a bus lane system. It has no setback provision, as there is not a left turning movement, and there is thus a small predicted disbenefit from the loss in junction capacity. However, the flow of buses was such that the nearside lane may have been only effectively used by buses anyway without the bus lane, and no disbenefits would then have occurred. Analysis of this section of the system may also not normally be undertaken in isolation.

The predicted disbenefits at *site* 22 were due to the high proportion of green time (0.68), the effect being similar to that described for site 18 above.

Site 23 forms an internal section of a bus lane system and, having only a small setback provision, some overall disbenefit is predicted from this loss in junction capacity. However, as with site 21, bus flows were high and little use may have been made of the nearside lane by other traffic even without the bus lane - if so, little disbenefit would have occurred. Again, it would be more usual to evaluate the complete bus lane system than a section of it in isolation.

The predicted benefits at *sites* 24 *and* 25, which are both contra-flow bus lanes, relate to two alternative modes of operation as discussed in Section 9.3.3.

9.5 OTHER ECONOMIC FACTORS

A number of other factors not quantified here may need to be considered in a rigorous economic analysis of a particular site.

Bus Passenger Waiting Time

Where a bus lane results in improved regularity and reliability of the bus service, bus passenger waiting times may be reduced at bus stops on the bus lane link and perhaps to some extent at bus stops downstream. More regular bus arrivals at a stop may also reduce passenger queue lengths at bus stops with a consequent reduction in boarding time. However, these effects are offset to some extent when congestion reduces towards the end of a peak period and bus headways are also reduced.

The quantification of these effects is difficult - research has mainly centred on bus routes in London where congestion is generally greater than elsewhere and where bus lane systems predominate rather than individual links.

Bus Passenger Walking Time

The relocation of bus stops which may accompany a bus lane scheme can provide significant savings in bus passenger walking time. This applies particularly to contra-flow lanes where buses are able to retain an existing route rather than being diverted around a one-way system with other traffic. Savings in walking time are related to the numbers of passengers boarding and alighting at the relevant stop(s) and the location of the stop(s) in relation to origin/destination locations.

Bus Service Reliability

An improvement in bus service reliability between days may be expected to benefit both passengers and operators and is often a key objective in the implementation of a scheme. Passengers may benefit from being able to plan their departure and arrival times more 'tightly', thus suffering less 'lost' time as well as from reduced anxiety connected with a less reliable service. Bus operators may benefit from a reduction in 'lost' mileage due to congestion and associated costs and from having a greater certainty in the journey times of buses which should aid scheduling and perhaps reduce the need for standby buses. The avoidance of disruption on only a few days a year would be a worthwhile benefit to both passengers and operators.

One problem in the valuation of such benefits has been that, although an individual bus lane may improve conditions for buses on that link, the bus route comprises many other links without bus lanes, and reliability benefits from the bus lane may be too small to quantify. The benefits to bus passengers are particularly difficult to quantify, but bus operators have valued these effects on their own operations in a number of cases. For example, at site 16 in Leeds, the West Yorkshire PTE considered that the savings in journey time and improved reliability of the service was notionally equivalent to around one bus in the schedule during the peak period, which could be interpreted as being worth about £25,000/annum. This applied to journey time savings of only around 100 seconds per bus.

Other Factors

Where a bus lane is introduced which significantly increases the level and variability of journey time for occupants of non-priority vehicles, there is likely to be additional disbenefit for these occupants. These may include increased 'lost' time through the need to allow a 'safety margin' of time for their trip, increased anxiety and uncertainty as to their optimum route on any day. These effects can be equally significant as those concerning improved reliability for bus passengers.

The economic effects of the loss of parking and loading/unloading provision or the restriction of access which may accompany the introduction of a bus lane may also be able to be estimated approximately (e.g. with reference to increased walking/journey time).

9.6 COMPARISON OF RESULTS WITH THOSE FROM PREVIOUS STUDIES

The studies carried out at TRRL into the economic justification of bus lanes using theoretical models[6,7] are briefly described in Section 2. For with-flow lanes, the main parameters found to control the levels of benefit were the degree of saturation of the junction, the setback provision, the flow of permitted users and the ease of diversion. These parameters have been confirmed in this study as being the most significant, particularly the first three. The results described in LR809[6] are in terms of warrants for implementation and guidance for assessing the merits of reserved lanes. The document was not intended as an evaluation tool for existing systems and, as expected, it could not readily be applied to the sites surveyed in this study. There were also significant differences between practical conditions on site and theoretical constraints within the theoretical modelling such as:

(i) Operating conditions at each site were unique and did not correspond with theoretical conditions tested. In particular:

- traffic intensity typically varied during a peak and sometimes exceeded one, a situation not modelled in LR809[6].
- the setback was sometimes non-optimum on site whereas LR809 considered the conditions of only an optimum setback or no setback. Diversion opportunities existing rarely fell into the categories considered in LR809.
- congestion at a number of sites was primarily due to exit blocking, which was not considered in the LR809 work.

For the reasons outlined above it has not been considered worthwhile to attempt to apply procedures/results reported in LR809 to the study sites.

The theoretical studies of contra-flow bus lanes described in LR918[7] found that the main factors controlling benefits were traffic volumes of priority and non-priority vehicles, savings in bus travel times and any increase in travel time for non-priority vehicles that may accompany, say, changes in junction design to accommodate the bus lane.

These findings have been confirmed here. However, the diversity in layout of contra-flow bus lanes was recognised in LR918 and results from this work have therefore not been applied to the study sites.

Three of the twelve with-flow bus lanes surveyed by Jamieson Mackay and Partners in their recent study[8] were included in the data base for this study. A comparison of the results of the evaluation of these three bus lanes is given below.

Site No.	Study	Measured Average Journey Time (secs/veh)		Time Savings (secs/veh)		Annual Benefit (£,000)
		Cars*	Buses**	Cars*	Buses	
3	Current	35	58	0	2	0.1
3	JMP	40	53	-7	0	-1.3
18	Current	77	60	-33	11	-32.3
18	JMP	56	60	-3	10	0.2
19	Current	38	71	0	0	0
19	JMP	71	69	-6	10	0.3

* and other non-priority traffic
** including bus stop time

Measured journey times for buses are relatively close between the two studies whereas those for non-priority traffic are noticeably different at sites 18 and 19. This is surprising in view of the larger sample size of non-priority vehicles which is obtained, but presumably reflects the effects on journey time of different levels of traffic intensity between days. The methods of modelling were dissimilar between the two studies (see Section 7.1.1) and this presumably accounts for the differences in predicted time savings and economic benefits.

TABLE 9.1 : RESOURCE VALUES OF TIME AND VEHICLE OPERATING COSTS (1985) BASED ON HEN2[20]

A. ECONOMIC PARAMETERS USED IN EVALUATION

VEHICLE TYPE	VALUE OF TIME (PENCE/HR)		VEHICLE OPERATING COSTS (NON-FUEL)* (PENCE/KM)		
	DRIVER	PASSENGERS	a	b	c
Buses/ Coaches	466	102	30.66	150.61	0.00015
Cars	183	164	3.83	23.99	0.000047
OGV	513		20.38	82.20	0.00014

* Vehicle operating costs (non fuel) $= a + \frac{b}{v} + cv^2$ pence/veh.km

Where v = speed (kph)

The fuel element of vehicle operating costs has been obtained from CONTRAM output, or calculated from the formula used within CONTRAM:

$$\text{Fuel consumption cruising (litres/veh.km)} = \frac{a_1}{10^3} - \frac{b_1 v}{10^5} + \frac{c_1 v^2}{10^7}$$

$$\text{Fuel consumption delayed (litres/veh.hr of delay)} = \frac{a_2}{10^2} + \frac{b_2 v}{10^4} + \frac{c_2 v^2}{10^6}$$

Where v = cruise speed (km/hr)

Values assumed for the co-efficients (as recommended in CONTRAM) are:

	a_1	b_1	c_1	a_2	b_2	c_2
Cars	164	240	200	150	107	340
Buses/OGV's	492	720	600	450	321	1020

Resource cost of fuel = £0.18/litre

B. ALTERNATIVE FIGURES FOR % JOURNEY STAGES IN THE COURSE OF WORK AND VALUES OF TIME

VEHICLE TYPE	OCCUPANT	TIME* PERIOD	% JOURNEY STAGES IN COURSE OF WORK	VALUE OF TIME (PENCE/HR)
Car	Driver	Peak	9.5	153
	Passenger		4.8	117
	Driver	Off-peak	13.6	178
	Passenger		2.9	108
Bus	Passenger	Peak	3.6	108
		Off-peak	1.4	100

* Peak : stages starting between 0700 and 0859 or between 1600 and 1659

Off-peak : stages starting between 0900 and 1559

TABLE 9.2 : AVERAGE VEHICLE OCCUPANCIES FOR EACH SITE

SITE NO.	PEAK/ OFF-PEAK	AVERAGE VEHICLE OCCUPANCY*				PERSON FLOWS PER HOUR**	
		BUSES	SAMPLE SIZE	CARS	SAMPLE SIZE	BUSES	NON-PRIORITY TRAFFIC
1 1	PEAK OFF	26.7 16.9	59 31	nr nr	nr nr	561 279	1195 900
2 2	PEAK OFF	22.9 15.6	95 54	nr nr	nr nr	710 437	1109 749
3	PEAK	33.1	152	nr	nr	728	1123
4 4	PEAK OFF	21.6 16.4	114 91	nr nr	nr nr	799 771	2700 2196
5 5	PEAK OFF	21.9 10.1	32 14	1.54 1.52	150 100	352 71	1186 935
6 6	PEAK OFF	24.0 14.7	63 50	1.58 1.49	174 70	504 352	1114 1244
7 7	PEAK OFF	30.9 18.8	56 27	1.38 1.34	347 211	556 263	1380 1052
8	PEAK	37.6	94	1.34	158	1166	1387
9	PEAK	35.2	94	1.37	435	1126	1021
10 10	PEAK OFF	14.5 16.0	190 95	1.49 1.47	302 133	899 784	2414 1566
11	PEAK	41.4	130	nr		1780	2146
12 12	PEAK OFF	33.2 22.5	240 118	1.42 1.32	165 140	2590 1238	2663 1591
13	PEAK	39.6	108	1.40	371	1505	1743
14	PEAK	22.1	47	1.37	328	332	1096
15 15	PEAK OFF	30.7 14.1	33 14	1.28 1.40	157 68	338 127	742 420
16	PEAK	35.1	72	1.40	530	913	1323
17	PEAK	38.7	70	1.35	434	851	1829
18	PEAK	37.4	176	1.35	194	2244	3821
19	PEAK	25.4	100	1.45	627	864	1037
20	PEAK	43.7	64	1.37	160	961	1617
21	PEAK	34.7	301	nr	nr	3470	936
22	PEAK	46.8	186	1.62	283	2995	1847
23	PEAK	35.4	285	1.67	304	3398	994
24 24	PEAK OFF	15.4 31.4	36 13	1.43 1.71	82 87	185 408	114 171
25 25	PEAK OFF	38.5 18.9	84 49	nr nr	nr nr	1232 463	1296 720

* nr = not recorded

** An average occupancy of 1-44 person has been assumed for non-priority vehicles where occupancies not recorded

TABLE 9.3 : ESTIMATES OF ANNUAL ECONOMIC BENEFITS AND MINIMUM IMPLEMENTATION COSTS FOR 1985

SITE[1] NO.	PREDICTED BENEFIT (£,000/ANNUM)[2]																MIN. COST[3] (£,000)
	PEAK						OFF-PEAK						OVERALL		
	NON-PRIORITY		PRIORITY		ALL TRAFFIC		NON-PRIORITY		PRIORITY		ALL TRAFFIC				
1	-0.9	-0.2	0.5	0.7	-0.4	0.5	0	-0.4	0	1.9	0	1.5	-0.4	2.0	1.5
2	-3.6	-0.4	0.6	1.6	-3.0	1.2	0	-0.2	0	0.7	0	0.5	-3.0	1.7	1.8
3	-0.1		0.2		0.1		N/A		N/A		N/A		0.1		1.3
4Δ	D	-2.5	D	8.6	D	6.1	D	-2.9	D	9.7	D	6.8	D	12.9	4.3
5	-0.3		1.2		0.9		-0.1		0.1		0		0.9		2.7
6	-2.2		5.9		3.7		-1.6		2.5		0.9		4.6		1.6
7	-1.5		6.4		4.9		-1.0		4.5		3.5		8.4		9.4
8	-0.8		2.7		1.9		N/A		N/A		N/A		1.9		0.9
9	-2.1		11.8		9.7		N/A		N/A		N/A		9.7		3.4
10Δ	-10.2	-1.8	1.8	4.0	-8.4	2.2	-6.1	-3.4	3.6	4.8	-2.5	1.4	-10.9	3.6	3.7
11*	-2.2	-0.1	0.2	0.6	-2.0	0.5	N/A		N/A		N/A		-2.0	0.5	3.6
12Δ	-1.7		7.8		6.1		0		0		0		6.1		4.0
13*	-0.1		0.6		0.5		N/A		N/A		N/A		0.5		1.4
14	-7.4	-1.0	0.4	1.6	-7.0	0.6	N/A		N/A		N/A		-7.0	0.6	3.7
15∇	2.3	D	2.3	D	4.6	D	0	D	10.8	D	10.8	D	15.4	D	-
16	-3.2		9.7		6.4		N/A		N/A		N/A		6.4		7.7
17*	D	-0.7	D	2.6	D	1.9	N/A		N/A		N/A		D	1.9	6.6
18	-35.8	-0.9	3.5	6.9	-32.3	5.9	N/A		N/A		N/A		-32.3	5.9	4.8
19	0		0		0		N/A		N/A		N/A		0		3.4
20	-5.0	-0.4	1.4	2.8	-3.6	2.4	N/A		N/A		N/A		-3.6	2.4	7.6
21	-0.2	0	0	0	-0.2	0	N/A		N/A		N/A		-0.2		2.1
22*	-8.3	-0.1	0	1.1	-8.3	1.0	N/A		N/A		N/A		-8.3	1.0	1.6
23	-0.5	0	0	0	-0.5	0	N/A		N/A		N/A		-0.5	0	1.8
24∇	0	-1.1	2.5	0.4	2.5	-0.7	0	1.2	14.0	-14.5	14.0	-1.1	16.5	-13.4	~2.2
25∇	21.0	-32.1	43.7	5.1	64.7	-27.0	0		22.5	-109.1	22.5	13.2	87.2	-95.9	-

1 Sites marked Δ have alternative 'without' bus lane layouts as described in Sections 8.5 and 9.3.1.
Sites marked ∇ are contra-flow sites.
Sites marked * are those where measured differences in journey time between priority and non-priority vehicles were not statistically significant.

2 Where two figures are given for with-flow sites, the first has been obtained from modelling and is the preferred result. Nevertheless, it has considerable associated uncertainty (see Sections 7 and 8), and a maximum benefit has therefore also been included, calculated as described in Section 6.2. Where one figure is given, this was obtained without modelling (Section 6.2) as no capacity loss due to the bus lane was considered likely. For contra-flow lanes, the first figure corresponds to buses being restricted to the one-way system while the second is where the bus lane is opened to all traffic (see Section 8.5).
Sites marked 'D' have disbenefits predicted which could not be accurately quantified (see Section 8.2.1).

3 Assuming the cost of a with-flow bus lane is £10 per metre. Costs were not known for the contra-flow sites 15 and 25.

NOTES : 1. All figures have been rounded to the nearest £100
2. See Section 9 for a fuller explanation of the table and Section 9.4 for a discussion of the results.

TABLE 9.4 : SENSITIVITY TESTS ON ECONOMIC BENEFITS

A. SENSITIVITY TO CHANGES IN 'WITHOUT' BUS LANE JOURNEY TIME PREDICTIONS

SITE NO.	OVERALL BENEFITS[1] (£,000/ANNUM)								
	1. PREDICTED JOURNEY TIME			2. AS 1. MINUS 5 SECS			3. AS 1 MINUS 10 SECS		
	CARS[2]	BUSES	TOTAL	CARS[2]	BUSES	TOTAL	CARS[2]	BUSES	TOTAL
8	-0.6	2.5	1.9	-1.7	1.9	0.2	-2.8	1.4	-1.4
9	-1.8	11.0	9.2	-2.6	10.4	7.8	-3.4	9.8	6.4
16	-2.4	9.0	6.5	-3.9	8.3	4.4	-5.3	7.7	2.4

B. SENSITIVITY TO CHANGES IN VEHICLE OCCUPANTS' VALUES OF TIME

SITE NO.	PEAK (P)/ OFF-PEAK (OP)	OVERALL BENEFITS[1] (£,000/ANNUM)					
		HEN2 VALUES*			ALTERNATIVE VALUES**		
		CARS[2]	BUSES	TOTAL	CARS[2]	BUSES	TOTAL
8	P	-0.6	2.5	1.9	-0.5	2.7	2.1
9	P	-1.8	11.0	9.2	-1.5	11.5	10.1
16	P	-2.4	9.0	6.5	-2.0	9.4	7.5
4	P	-1.9	7.7	5.8	-1.5	8.1	6.6
4	OP	-2.0	8.7	6.6	-1.8	8.5	6.7

* TABLE 9.1A
** TABLE 9.1B

1 Time costs only
2 and other non-priority traffic

NOTE: 1. All figures have been rounded to the nearest £100.
2. Figures reflect time savings only and exclude vehicle operating cost savings.

SECTION TEN

CONCLUDING COMMENTS

EVALUATION METHODS/CRITERIA

The emphasis of the study has been on the assessment of the suitability of three computer-based traffic models for the evaluation of bus lanes - TRAFFICQ, CONTRAM and BLAMP. These programs are described in Section 7. A possible method of evaluation not based on computer modelling is also described, together with circumstances where its use may be appropriate (Section 7.5). Evaluation procedures developed in this study are set out in Appendix E and illustrated in Appendix F.

The main evaluation criteria have been the effects of the bus lane on travel times and associated costs, although other criteria are also considered. Travel time savings for priority vehicles have been related to reductions in queueing time (for with-flow bus lanes) and also in distance-related travel time (for contra-flow bus lanes). Other factors which may be significant and which should be considered during evaluation are described in Appendix E. The assessment has been based on data collected at 25 bus lanes throughout the U.K. (as described in Appendix A).

Evaluations have been based on the assumption that traffic conditions and junction control were the same before and after the introduction of the bus lane(s) (e.g. there was no change in traffic flows, signal timings, etc.). In practice, some changes may have occurred on implementation which would normally be incorporated into an evaluation procedure.

For with-flow bus lanes, evaluations have generally been carried out on the bus lane links in isolation, although it should be noted that some links may have been introduced partly to relocate queues from more'critical' junctions downstream. Some loss of capacity and increase in delay on the bus lane link, due to the bus lane, may therefore not have been wholly unintentional but should be quantified.

MODELLING

In principle, an appropriate computer model is considered to have the advantages that:

(i) A consistent methodology for within and between site appraisals should be possible.

(ii) The important factors controlling traffic performance are highlighted.

(iii) A variety of strategies/designs can be assessed relatively quickly.

(iv) More complex situations can be analysed than is possible 'manually' (e.g. consecutive bus lane links, blocking back of upstream junctions, traffic diversions, etc.)

These advantages have been confirmed in the models tested subject to a number of qualifications and areas of uncertainty described below and in the accompanying text.

Computer modelling does not remove many of the uncertainties associated with alternative networks (e.g. queueing behaviour in the setback, changes in vehicle speeds, diversion behaviour, etc.) and predictions should be treated accordingly. These uncertainties can only be reduced through observation of the relevant parameters 'before' and 'after' the implementation of a bus lane, and increased emphasis in this area is recommended. At the least, each scheme should be monitored after its introduction and modified if necessary.

WITH-FLOW BUS LANES : BLAMP

For a single with-flow bus lane link, BLAMP has the advantages over the other models that:

(i) It is simple to use, concentrating solely on features relevant to the bus lane, and requires minimal computing resources (see Section 7.3).

(ii) The 'stepped' discharge profile (e.g. Figure 7.3) which occurs with short setbacks is represented explicitly within the model whereas TRAFFICQ and CONTRAM require average values to be input.

(iii) The value of any input parameter can be varied at any time during the modelling.

It is possible that BLAMP could also be used to evaluate a with-flow bus lane system containing a series of connected links by analysing each link separately, although this has not been attempted in this study. An obvious limitation would be where traffic on one link queues back into an upstream link, as this interaction cannot currently be analysed within BLAMP.

The assessment of BLAMP has been limited in this study however, and further development/assessment of the model is considered worthwhile before its general use.

It is also possible that programs such as ARCADY, PICADY or OSCADY would be suitable for evaluating single with-flow bus lane links as they offer more detailed modelling of individual junctions - usually the most critical component - than either BLAMP or the two network orientated models, TRAFFICQ and CONTRAM.

WITH-FLOW BUS LANES : TRAFFICQ AND CONTRAM

Sensitivity tests on the models have shown that the representation in TRAFFICQ and CONTRAM of a link containing a with-flow bus lane is best achieved by maintaining a single link and reducing the number of lanes (TRAFFICQ - Figure 7.2) or link storage capacity (CONTRAM - Figure 7.7) accordingly, rather than introducing artificial junctions at the beginning and end of the bus lane (e.g. Figures 7.1 and 7.7). The latter approach can lead to unstable results with both models (see Sections 7.1.1 and 7.2.1). However, the benefit of the bus lane to priority vehicles is not obtained directly using this approach, and has to be calculated separately (e.g. as in Section 7.1.1).

TRAFFICQ and CONTRAM are considered to represent the effects of a with-flow bus lane adequately where either no setback is provided or where the setback is of sufficient length not to reduce junction capacity. However, neither model correctly represents traffic discharge from setbacks which are too short for the number of vehicles which could discharge in a green phase (e.g. Figure 7.3). With additional uncertainties in queueing behaviour under these conditions (as described in Section 6.4), unreliable results are possible from these models.

There may also be difficulties in accurately modelling the effects of a bus lane introduced within a network controlled by a UTC system: Traffic progressions may be affected (which cannot be modelled within CONTRAM) and with an on-line system such as SCOOT, appropriate variations in signal timings cannot be accurately modelled by either program.

If TRAFFICQ is used, at least two runs are recommended to assess the random variation in mean journey times and, where this variation is high (as is likely under congested conditions), more runs would be needed to obtain an acceptable 'average' result.

Both TRAFFICQ and CONTRAM were designed for modelling traffic networks and are clearly more appropriate for this purpose than for modelling single links, where other models described in 4 above are likely to be more suitable.

WITH-FLOW BUS LANES : FACTORS AFFECTING BENEFITS

The main factors affecting the level of benefit of *a with-flow bus lane* have been found to be the level of flow and occupancy of priority vehicles, traffic intensity (i.e. the ratio of demand to capacity) and setback distance. The proportion of green time allocated to the link is also of key importance. If it exceeds about 0.6 of the total cycle time, junction capacity will be reduced as there is insufficient red time to allow the setback to be re-filled, and overall disbenefits will inevitably occur (e.g. as at site 18). Greatest benefits have occurred where traffic intensity is highest, but capacity is unaffected by the bus lane. This has been observed where, for example, an adequate setback has been provided or where conditions immediately downstream of the bus lane link control its capacity (e.g. an exit constriction, such as a bridge crossing).

The 'rule of thumb' in H6/76 that the setback distance in metres should be twice the effective green time has been found to be inappropriate in many situations. It is recommended that the setback distance be governed by the average number of vehicles observed to discharge over a number of saturated green periods before the bus lane is introduced, or, in the case of a roundabout, by consideration of the maximum number of vehicles able to accept a gap in the circulating traffic under saturated conditions. Actual setback usage should then be monitored after implementation.

Setback distances have been found to be inappropriate for the signal timings at some sites (see Section 6.3) and it is possible that timings (or the form of signal control) have been ammended since these bus lanes were introduced, often some 10 years ago. Improved performance could be achieved either by adjusting the setback distance or by altering the signal timings; the latter option may require consideration to be given to the effects on competing traffic movements at the junction, or it may not be practical to implement (e.g. within traffic responsive systems such as SCOOT).

Although with-flow bus lanes are more consistent in layout between sites than contra-flow lanes, general warrants for their implementation (as are given in LR809) have not been sought within the resources of the study. Difficulties would clearly occur in attempting to generalise the effects of variations in traffic intensity during the operational period of the bus lane and of defining 'optimum' setback distances in different circumstances (e.g. of exit blocking), conditions which are common in practice.

CONTRA-FLOW BUS LANES

The case for computer modelling is stronger for the evaluation of contra-flow than for with-flow bus lanes, as the systems not only involve re-routing but also usually require junction modifications and may lead to traffic re-assignment to the adjacent network. Also the numerous alternative layouts which are likely can be more easily assessed. Either TRAFFICQ or CONTRAM can be used for evaluation, although CONTRAM may be more suitable as it can model larger networks, a greater choice of routes and carries out traffic assignment to these routes within the model. It can also optimise signal timings (if desired) to cater for variations in demand flows/traffic assignment.

The main factors affecting the level of benefit of a contra-flow bus lane have been found to be the distance (and associated time) savings for buses and the difference in operational characteristics of the 'with' and 'without' bus lane situations (e.g. permitted routes for non-priority traffic, junction characteristics, etc.). At the three contra-flow bus lanes surveyed (site nos. 15, 24 and 25) distance savings to buses were 100m, 160m and 250m respectively, equivalent peak period time savings (compared to other traffic) being, on average, 14 secs, 62 secs and 155 secs per vehicle. However, these savings need to be assessed against alternatives (as discussed in Section 8.5) including the opening of existing lanes to all traffic, which limited analysis indicates could give the greatest overall time savings. Each scheme is unique, and it is not considered practicable to produce general warrants for implementation.

MODELLING OF ROUNDABOUTS

Schemes involving roundabouts or priority junctions, can also be evaluated using CONTRAM or TRAFFICQ. Where a setback is provided, it can be considered as a flare, and its effect on capacity calculated accordingly (Section 7.1.1). However, there is evidence to suggest that this approach may lead to an overestimate of the reduction in capacity due to a bus lane, particularly where circulating flows are high (Section 8.4.1.2). Measurement, as described in note 6 above, is therefore recommended. The modelling of roundabouts within BLAMP is less certain, however. At high levels of traffic intensity, delays are usually higher at a junction if it is controlled by a roundabout rather than traffic signals (depending on such factors as the level of circulating traffic and signal timings). Thus, where a roundabout is operational in such circumstances, the potential benefits of a bus lane may be higher than with signal control, although converting the junction to signal control may give greater overall benefits (i.e. by reducing delays to non-priority traffic).

CALIBRATION

The accurate representation in a computer model of existing traffic conditions in a network in which a bus lane is operating, or being considered, is important if a meaningful comparison is to be obtained between alternative layouts. This representation has been found to be time consuming, as, with the network typically operating at around capacity, even small errors in input parameters can have a significant effect on predicted conditions (e.g. queue lengths, delays, etc.). Accurate estimates of parameters such as demand flows, saturation flows and vehicle speeds are required and it is recommended that measurements (rather than predictions) of these parameters be made. Even then, some 'calibration' of the model (typically the relevant saturation flows) may be required to achieve a sufficiently accurate reflection of existing conditions.

Where congestion on a bus lane link is caused by intermittent exit blocking, the bus lane may still restrict capacity during periods when the exit is clear, and modelling may be required for evaluation. Under these circumstances, capacity is likely to vary according to the degree of exit blocking. If this occurs, downstream links have to be included in the modelled network. The accurate representation of this in TRAFFICQ or CONTRAM is likely to be particularly difficult. In

BLAMP it is possible to simulate this situation by varying the saturation flow parameters at set intervals during the modelling, to reflect observed conditions.

EXPERIMENTAL LAYOUTS

It is noted that a number of bus lanes were initially introduced on an experimental basis partly due to the uncertainty in their likely performance. A key area of uncertainty is the extent to which the bus lane will reduce junction capacity particularly at roundabout entries and experimentation in this area could well be worthwhile using temporary road markings. For example, traffic cones could be used to represent the downstream end of a proposed bus lane and the effects of different setback distances on entry capacity (or journey times/delays) could be monitored, and the optimum setback distance determined prior to more 'permanent' road markings.

ECONOMIC BENEFITS

Measured maximum journey time savings for the with-flow bus lanes considered in this study have varied considerably between sites, from £0 to £13,000 per annum for the different sites (Table 9.3). However, where the bus lane was introduced by the construction of an additional lane, much higher benefits were predicted although implementation costs would have been higher. Where a bus lane has been considered to reduce junction capacity (at some 50% of the with-flow lanes studied) overall disbenefits have usually been predicted to exceed the maximum possible benefits, by a large margin (Table 9.3). However, it should also be noted that, in some cases, delay to non-priority traffic on a bus lane link may be increased by the introduction of a bus lane but that delay on formerly more critical links downstream may be reduced. (This has been predicted from limited computer modelling, and would be expected in practice.) The bus lane link should not then be evaluated in isolation as has been carried out here.

The overall benefits of the contra-flow bus lanes varied according to the assumptions made about the 'without' bus lane situation (Table 9.3). Thus, the bus lanes generally produced a large disbenefit if they were assumed to cause non-priority vehicles to divert to a longer route, but produced a large benefit if they were assumed to allow buses to use a shorter one.

The benefits calculated here are subject not only to uncertainties associated with the modelling, as described above but also to the limitations associated with extrapolation from 2 days results to those for a year. It is likely that parameters such as traffic flow will be particularly variable throughout the year, giving rise to different operating conditions which may need to be considered during the evaluation. Changing circumstances on adjacent streets, such as junction improvements, which may affect the operational performance of the bus lane link (e.g. through the removal of exit blocking or the reduction in traffic demand) also have to be considered.

With the relatively low cost of implementation, a with-flow bus lane can typically pay for itself within a year if journey time savings for buses averaging only around 30 seconds per bus during a peak period can be achieved without disbenefitting other traffic. However, all benefits can be lost if other traffic suffers an increase in journey time of only around 5 to 10 seconds in a peak period. With small time changes having such significant effects, uncertainties in the modelling have to be considered throughout the evaluation, particularly where economic benefits are marginal.

Conditions observed in the study where a with-flow bus lane has been introduced and is considered to give a net benefit even where flows of priority vehicles are low include:

- Where an adequate setback is provided
- Where a tapered entry exists (e.g. at a bridge crossing)
- Where exit blocking controls capacity

The observed/predicted effects of the bus lane considered in this study relate to operational characteristics existing. Variations in the operational characteristics of bus services such as may follow deregulation of bus operations may significantly effect the benefits of bus lanes (e.g. a greater number of lower capacity buses, which may operate to more flexible schedules, could cause increased congestion both in the bus lane and in general).

OTHER EVALUATION CRITERIA

Criteria other than travel time and associated cost may also need to be considered in an evaluation procedure, including:

(i) Safety

From the evidence available (e.g. as in Reference 12) accident rates have been observed to increase slightly immediately after the introduction of a scheme but to then settle to the same or a slightly lower level as before. Attention to detail at the design stage has been recognised as important to reduce accident risk.

(ii) Environmental Impact

This is related mainly to the degree to which a bus lane causes traffic to re-assign through environmentally sensitive areas. A comprehensive evaluation procedure, if required, is given in Reference 22.

(iii) Effects of Parking/Access Restrictions etc.

The requirement and methods for evaluating these effects have to be assessed for each site. Such items as the increase in walking time for shoppers/residents and loss of revenue for affected businesses may be significant.

OTHER SURVEY RESULTS/COMMENTS

(i) Operational Periods

These varied at the study sites being either peak period only (morning and/or evening), 12 hours or 24 hours (Table 5.1). The majority of with-flow bus lanes (55%) operated during a peak period only while all of the contra-flow lanes operated continuously. The bus lanes were found to have greatest effect, in terms of time savings, in peak periods (whether beneficial or otherwise) although in some cases smaller off-peak effects per hour were more significant when aggregated. The advantages and disadvantages of adopting different operational periods are discussed in H6/76.

(ii) Bus Lane Usage

Stage carriage buses and pedal cycles (where allowed) were observed to be the predominant users of bus lanes, comprising, on average, some 3.3% and 4.4% of total traffic volumes respectively. There were considerable variations between conurbations, however, maximum recorded percentages being 13% and 20% respectively. Where taxis were permitted their volumes never exceeded 1% of total traffic (in contrast to central London) and emergency vehicles were, by nature, rarely recorded (although the bus lane could have been of major benefit to these vehicles). With such low usage of bus lanes, it may be worthwhile to extend their use to other vehicles which have higher than average resource cost, such as commercial vehicles or cars with high passenger occupancies.

(iii) Violations/Enforcement

Parking violations were only considered to reduce the effectiveness of the bus lane significantly at two sites, a 12 hour bus lane where off-peak loading/unloading was common and an evening peak site where parking permitted during off-peak periods continued illegally during the peak. Such violations are related to frontage activity, and alternative loading/parking provision should feature at the planning stage. The necessity for regular enforcement of parking restrictions is clearly undesirable.

Moving violations over at least half of the bus lane's length averaged 4% in peak periods. It was also found that these violations increased by around 2% for every 100 second increase in delay per kilometre of bus lane for non-priority traffic.

(iv) Vehicle Occupancies

The average car occupancy recorded in all surveys was 1.44, no significant difference being found between peak and off-peak periods. Average bus occupancies recorded in peak and off-peak periods were 32 and 18 respectively. These are significantly higher than the average value of 15.67 given in HEN2, and indicate that site specific occupancies are required for an accurate economic evaluation.

ALTERNATIVE SIGNAL SETTINGS

Signals are conventionally set in the U.K. to minimise vehicular delay and to distribute this delay equally between vehicles on different arms. However, where bus flows are different between arms it may be more economically efficient to minimise passenger delay, which could require different signal settings (typically, more green time would be allocated to the stage with higher bus flows). This optimisation of junction operation should be undertaken before a bus lane is considered, to prevent the true value of the bus lane being exaggerated.

In practice, the scope for 'biasing' signal timings in favour of arms with high bus flows may be limited, as, with junctions typically operating at around capacity at with-flow bus lanes additional delay to non-priority arms would soon be overwhelming if their green time was substantially reduced. However, the example of this passenger optimisation criteria described in our parallel study of 'Bus Priority by Selective Detection' which is being published concurrently with this report, indicated that worthwhile passenger delay savings could be achieved using this technique, particularly where bus flows are high.

MINIBUS OPERATION

In recent years, there has been a shift towards minibus operation by some bus operators, these buses offering a faster, more frequent service with greater penetration of residential areas. The introduction of minibuses, which is likely to accelerate following bus deregulation, requires many more buses to be operational to provide the same seating capacity. (Typically three times as many buses would be required, doubling the bus flow in terms of passenger car units.) The implications of this in terms of the operational performance of bus lanes are discussed in our concurrent study of 'Bus Priority by Selective Detection'.

In summary, minibuses may benefit more from bus lanes than conventional buses through being able to maintain higher average speeds (e.g. due to their performance characteristics and reduced width making them less affected by such factors as cyclists, narrow lanes and other queueing vehicles alongside encroaching into the bus lane). On the other hand, congestion in the bus lane could occur where bus flows are particularly high and/or at bus stops. The effects on non-priority traffic can only be detrimental; with-flow bus lanes typically operate on links with traffic flows at around capacity levels and being overtaken by three times as many buses could cause significant additional delays to non-priority traffic. It is worth noting that, where this causes non-priority queue lengths to exceed the length of the bus lane, buses themselves would also suffer increased delay.

FURTHER RESEARCH

Areas of useful further research are considered to be related to:

- The uncertainties surrounding key operational characteristics such as the effect of bus lanes on the speeds of priority and non-priority vehicles and on queueing behaviour in the setback under different circumstances. This could be achieved by measurements of specific items at a large number of sites and/or further analyses of relevant 'before' and 'after' data which has been collected nationally.
- The development and further assessment of BLAMP.
- The assessment of the potential of other models for the evaluation of bus lanes, particularly ARCADY, PICADY and OSCADY.
- The performance of bus lanes on links controlled by traffic responsive signals such as isolated vehicle actuation or SCOOT (e.g. optimum setback design, effects on traffic progressions, etc.).
- Accident statistics associated with bus lanes.
- Benefits/disbenefits of bus lanes outside their operational period so that optimum operational periods can be determined.
- The effects of deregulation on the effectiveness of bus lanes (e.g. by undertaking 'before and after' studies).

ACKNOWLEDGEMENTS

We should like to express our thanks to Mr. P. Kompfner of the Transport Planning Division of the Transport and Road Research laboratory who, as Project Officer, gave considerable guidance and advice during the course of the study. We should also like to thank:

- Mr. A. Doherty of the Traffic Policy Division of the Department of Transport for his helpful comments on the report.
- Mr. G.D. Robertson of West Yorkshire Metropolitan County Council for providing a copy of the BLAMP program for evaluation and for his associated help and advice.
- Mr. K. Lewis of the Consultants Colin Buchanan and Partners for stimulating discussion during the study.
- Mr. M. Logie of the Consultants MVA Systematica for his advice concerning aspects of the TRAFFICQ program.
- The Public Transport Managers of the Bus Companies operating in the areas listed below, for their helpful comments and information.
- The many staff of the Local Authorities contacted during the course of the study, who provided advice and information on a variety of aspects of bus lane operation and evaluation in their areas, including drawings, Committee reports and Traffic Regulation Orders. We wish to thank the following Authorities and personnel:

. Hampshire County Council	:	Mr. Gregory and Mr. Akers
. Southampton City Council	:	Mr. Nicholson, Mr. Logan & Mr. Palmer
. Portsmouth City Council	:	Mr. Easterling, Mr. Head & Mr. Banks
. Oxfordshire County Council	:	Mr. Kearney
. Oxford City Council	:	Mr. Nuson
. Avon County Council	:	Mr. Godwin and Mr. Mitchell
. South Glamorgan County Council	:	Mr. Williams, Mr. Bailey & Mr. Graytricks
. Berkshire County Council	:	Mr. Barr
. West Midlands Metropolitan County Council	:	Mr. Meredith
. Leicester City Council	:	Mr. Pepper & Mr. Pritchard
. Derby City Council	:	Mr. Goddard
. Nottinghamshire County Council	:	Mr. Payne, Mr. Bloor & Mr. Chatfield
. West Yorkshire Metropolitan County Council	:	Mr. Hunter, Mr. Robertson & Mr. Pearson
. Lothian Regional Council	:	Mr. Toole

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APPENDIX A

DATA BASE

This Appendix is contained in a separate document
as Transport Planning Division Working Paper WP(TP)50

APPENDIX B

EXAMPLE OUTPUTS FROM MODELS

APPENDIX B

EXAMPLE OUTPUTS FROM MODELS

This Appendix contains examples of the input/output from the application of TRAFFICQ, CONTRAM and BLAMP to selected sites. These examples included are:

(i) Site No. 16 (with-flow bus lane) : TRAFFICQ
(ii) Site No. 18 (with-flow bus lane) : BLAMP
(iii) Site No. 25 (contra-flow bus lane) : CONTRAM

(i) Site No. 16 - TRAFFICQ

The coding of this site is given in Figure B1, followed by the TRAFFICQ data input and output. The modelling has been simplified in this example to exclude the effects of the free left turn and of the pedestrian (zebra) crossing, both of which were minimal. The right turn movement was prohibited. The traffic flow modelled is therefore simply that travelling from origin 1 to destination 3. The coding shows a queueing point at the start of the bus lane (and one immediately opposite) to allow observed and predicted journey times to be compared directly - this queueing point would normally be excluded.

The input data has been divided into its main elements - a more detailed interpretation can be obtained from the TRAFFICQ user manual. Reference to this manual may also be required for explanation of the output, although this is largely self-explanatory. The queue lengths and journey times of interests are those on links 1 and (particularly) 5.

The estimation of the journey time for buses is based on the table showing the variation of queue length with time for link 5. (Had the queue on link 5 ever exceeded the length of the bus lane, it would have been necessary to include the effects of buses having to queue before reaching the bus lane.) The setback distance for this bus lane is 124 metres, and, as the setback is fully used by non-priority traffic, buses may be considered to gain no advantage from the bus lane unless the average queue exceeds 124 metres. This occurs for the last 60% of the modelled period (see highlighted table in the output). The calibrated discharge rate of the link is 1034 vehs/hr (or 0.287 vehs/sec) and the following journey time savings for buses are obtained (assuming 1 queueing vehicle takes up 5.5m of road space).

Time Interval:	1	2	3	4	5	6	7	8	9	10
Av. Queue (m)	24	38	56	96	126	195	302	368	304	364
Av. No. of Vehs. Overtaken by Buses	0	0	0	0	0	13	32	44	33	44
Saving for Buses (secs)	0	0	0	0	0	45	111	153	115	153

This saving can then be weighted by the number of buses in each time interval. If this number was the same between intervals, the overall saving would be simply the average of the figures in the bottom row of the above table. This figure, when subtracted from the predicted average journey time for non-priority vehicles (given in a highlighted table) gives an estimate of the average journey time for buses. A similar technique to this is used when modelling with CONTRAM, except that queue lengths output by CONTRAM are already in terms of vehicles.

(ii) Site No. 18 - BLAMP

This with-flow bus lane is illustrated in Appendix A. BLAMP can cater for either 2 or 3 lanes at the stop line and it has therefore been necessary to exclude the effects of right turning vehicles in this example (these effects were observed to be minimal). The modelling of this link by BLAMP is illustrated in Figures B2 and B3 which were obtained by stopping the simulation procedure during the modelling and printing out the contents of the visual display. Figure B2 shows the build up of the queues during the red period while Figure B3 shows the way in which a 'gap' can develop between the stop line queue and the queues at the end of the non-priority lanes adjacent to the bus lane (e.g. if saturation flows are lower at this point). The input parameters for the model (and their values) are given in the 'User' and 'Expert' menus, listed in Figures B2 and B3 respectively. Output is in the form of queue lengths and delays for the different sections of the link for each cycle as shown in Figures B2 and B3. Average overall delays for cars and buses can also be printed out on a cyclic basis and as overall averages for the modelled period.

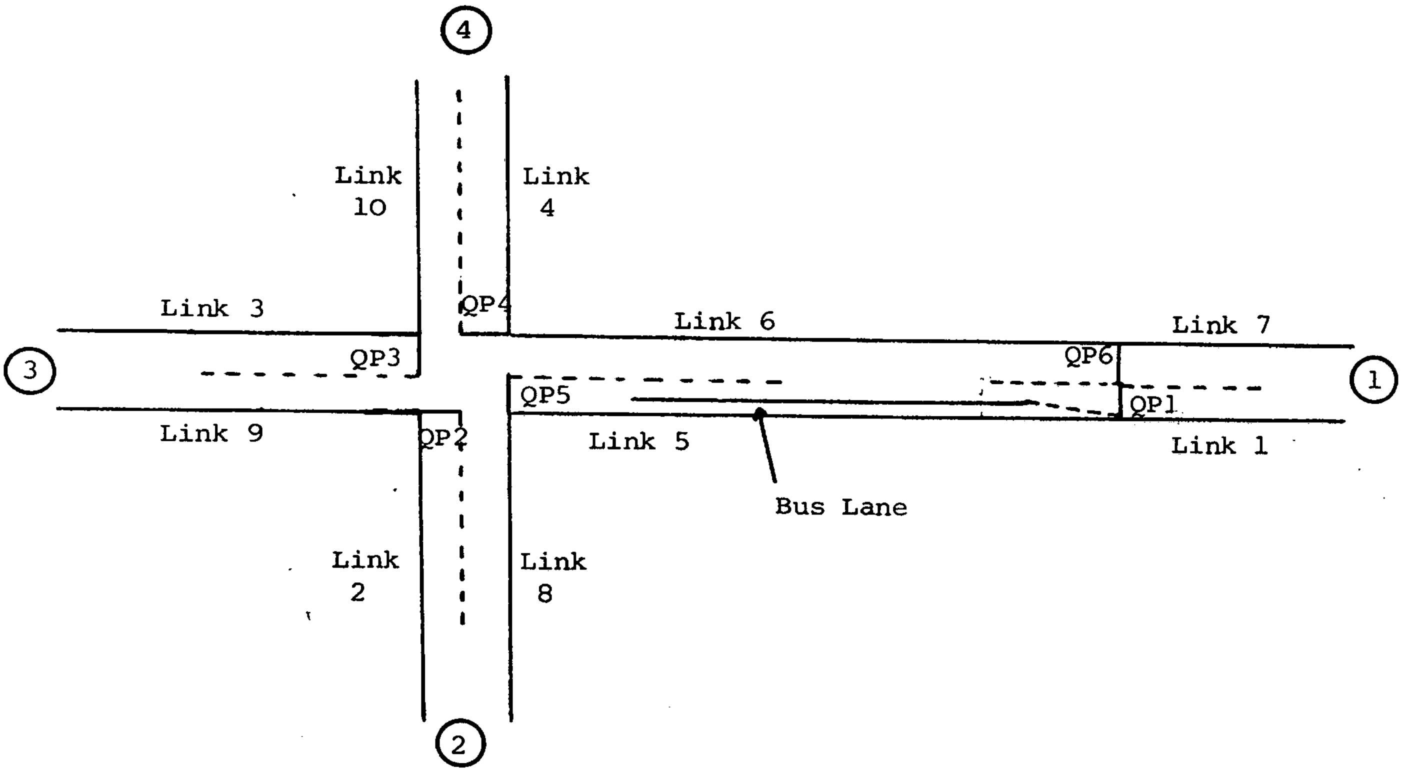
(iii) <u>Site No. 25 - CONTRAM</u>

The Kings Road contra-flow bus lane in Reading (Site No. 25) is illustrated in Appendix A, the CONTRAM coding of the relevant links in the network being given in Figure B3. The output from CONTRAM which follows has been abridged to show one example of each relevant table.* Again, the output is largely self explanatory, although the principle items are highlighted for clarity. These broadly include (in order of output):

i) Input data : network and time information, traffic demand data and control data.
ii) Summaries of overall network results : journey time (veh.hrs), distance travelled (veh.kms), speed and fuel consumption.
iii) Convergence monitors to check stability of assignment (excluded from this example).
iv) Link-by-link results for each time interval (time intervals 1 and 5 only are included here for brevity).
v) Summary tables of arrival flows, final queues, average queue times (delays), average speeds and turning movements for each link in each time interval.

Vehicle journey times on each link are obtained by adding the cruise time to the delay for each time interval, allowing an overall flow weighted journey time for each link/route to be determined. In this example, buses on the contra-flow lane use links 301, 601, 702 and 902, while other traffic travelling from origin 5001 to destination 9002 use links 201, 301, 401, 802 and 901.

FIGURE B1 : TRAFFICQ CODING - SITE 16



TRAFFICQ INPUT DATA : SITE 16

Control Data

```
ROUNDHAY ROAD BUS LANE: LEEDS
   6  10   4   2
   3   8   4   5
9999  93   0   4
   2   2   0
  20  20 400
 300 100  80
  5.5000  1.0000   .1000  1.5000   .0080
   1   0   2 200 APPROACH LINK
   5   0   2 200 BUS LANE LINK
   1   0   5 500 APPROACH LINK
   5   0   5 500 BUS LANE LINK
NO MULTI
```

Origin-destination flow in 1st time interval

```
    0    0  604    0
    0    0    0    0
    0    0    0    0
    0    0    0    0
```

Time intervals for simulation

```
 300    1.00  90099.00  90099.00  90099.00  90099.00  90099.00  900
```

Link dimensions and cruise speeds

```
   1    100 2.0 100 2.0 100 2.0  17   4
   2    100 2.0 100 2.0 100 2.0  12   3
   3    100 2.0 100 2.0 100 2.0  12   3
   4    100 2.0 100 2.0 100 2.0  12   3
   5    355 1.0 355 1.0 126 2.0  17   4
   6    355 1.0 355 1.0 126 1.0  17   4
   7    100 2.0 100 2.0 100 2.0  12   3
   8    100 2.0 100 2.0 100 2.0  12   3
   9    100 2.0 100 2.0 100 2.0  12   3
  10    100 2.0 100 2.0 100 2.0  12   3
```

Saturation flows

```
   1       0 1800    0 3600
   2    3600 3600 3600 3600
   3    1800 1800 1800 1800
   4    1800 1800 1800 1800
   5    3970 3970 3970 3970
   6       0 3600    0 3600
```

Schedule of routes

```
   1   1   0   0   1   2   5   8   1   3   5   9   1   4   5  10
   2   1   6   7   2   2   0   0   2   3   9   0   2   4  10   0
   3   1   6   7   3   2   8   0   3   3   0   0   3   4  10   0
   4   1   6   7   4   2   8   0   4   3   9   0   4   4   0   0
```

Schedule of link connections

```
   1       5           6
   2   9  10   6   3   4   5
   3  10   6   8   4   5   2
   4   6   8   9   5   2   3
   5   8   9  10   2   3   4
   6       7           1
```

Signal timings

```
   1   0 120   0
   2  40  87  33
   3   0  33  87
   4  40  87  33
   5   0  33  87
   6   0 126   0
```

Origin-destination flows for 2nd to 6th time intervals

```
    0    0  988    0
    0    0    0    0
    0    0    0    0
    0    0    0    0
    0    0 1024    0
    0    0    0    0
    0    0    0    0
    0    0    0    0
    0    0  908    0
    0    0    0    0
    0    0    0    0
    0    0    0    0
    0    0  992    0
    0    0    0    0
    0    0    0    0
    0    0    0    0
    0    0  980    0
    0    0    0    0
    0    0    0    0
    0    0    0    0
```

TRAFFICQ OUTPUT FOR SITE 16

TRAFFICQ - VEHICLE AND PEDESTRIAN DYNAMIC SIMULATION MODEL

PROGRAM TRAFFICQ VERSION 2 MODIFICATION 9

PROGRAM LICENSED TO - University of Southampton

SHIRLEY ROAD: CARS ONLY WITH BUS LANE

T R A F F I C Q R E S U L T S
==============================

DYNAMIC-STOCHASTIC SIMULATION OF TRAFFIC AND PEDESTRIAN ACTIVITY IN ROAD NETWORKS

90 MINS. 0 SECS. OF OPERATION SIMULATED

SHIRLEY ROAD: CARS ONLY WITH BUS LANE

QUEUE WAITING BY APPROACH LINK LINK NO. 1 (TAILBACK IN METRES)

FLOW ENTERING = 1016VPH, FLOW LEAVING = 1010VPH, LINK LENGTH = 300M

COUNT	RANGE			CUMULATIVE DISTRIBUTION (AS A PERCENTAGE) COUNT	RANGE		
337	0	TO	2	100	0	TO	2
0	3	TO	4	34	3	TO	4
91	5	TO	6	34	5	TO	6
45	7	TO	8	16	7	TO	8
0	9	TO	10	7	9	TO	10
19	11	TO	12	7	11	TO	12
15	13	TO	14	4	13	TO	14
2	15	TO	16	1	15	TO	16
0	17	TO	18	0	17	TO	18
1	19	TO	20	0	19	TO	20
1	21	TO	22	0	21	TO	22
0	23	TO		0	23	TO	

MEAN = 3.1 STANDARD DEVIATION = 3.4 (110.9%)

VARIATION OF QUEUE LENGTH WITH TIME (% OF SIMULATION PERIOD)

FOR APPROACH LINK LINK NO. 1 LINK LENGTH = 300M

ALL VEHICLES MEAN LENGTH(M)	TIME	RIGHT TURNERS MEAN LENGTH(M)	TIME	FILTER VEHICLES MEAN LENGTH(M)	TIME
1	0 TO 10	0	0 TO 10	0	0 TO 10
3	11 TO 20	0	11 TO 20	0	11 TO 20
3	21 TO 30	0	21 TO 30	0	21 TO 30
2	31 TO 40	0	31 TO 40	0	31 TO 40
3	41 TO 50	0	41 TO 50	0	41 TO 50
4	51 TO 60	0	51 TO 60	0	51 TO 60
2	61 TO 70	0	61 TO 70	0	61 TO 70
3	71 TO 80	0	71 TO 80	0	71 TO 80
3	81 TO 90	0	81 TO 90	0	81 TO 90
3	91 TO	0	91 TO	0	91 TO

MEAN = 2.7 MEAN = 0.0 MEAN = 0.0

SHIRLEY ROAD: CARS ONLY WITH BUS LANE

QUEUE WAITING BY BUS LANE LINK LINK NO. 5 (TAILBACK IN METRES)

FLOW ENTERING = 1010VPH, FLOW LEAVING = 954VPH, LINK LENGTH = 836M

		CUMULATIVE DISTRIBUTION (AS A PERCENTAGE)	
COUNT	RANGE	COUNT	RANGE
11	0 TO 2	100	0 TO 2
0	3 TO 4	98	3 TO 4
6	5 TO 6	98	5 TO 6
6	7 TO 8	97	7 TO 8
0	9 TO 10	95	9 TO 10
3	11 TO 12	95	11 TO 12
5	13 TO 14	95	13 TO 14
6	15 TO 16	94	15 TO 16
0	17 TO 18	93	17 TO 18
7	19 TO 20	93	19 TO 20
5	21 TO 22	91	21 TO 22
4	23 TO 24	90	23 TO 24
0	25 TO 26	90	25 TO 26
4	27 TO 28	90	27 TO 28
4	29 TO 30	89	29 TO 30
0	31 TO 32	88	31 TO 32
11	33 TO 34	88	33 TO 34
5	35 TO 36	86	35 TO 36
6	37 TO 38	85	37 TO 38
0	39 TO 40	84	39 TO 40
5	41 TO 42	84	41 TO 42
5	43 TO 44	83	43 TO 44
12	45 TO 46	82	45 TO 46
0	47 TO 48	79	47 TO 48
4	49 TO 50	79	49 TO 50
9	51 TO 52	79	51 TO 52
0	53 TO 54	77	53 TO 54
6	55 TO 56	77	55 TO 56
5	57 TO 58	76	57 TO 58
7	59 TO 60	75	59 TO 60
0	61 TO 62	73	61 TO 62
3	63 TO 64	73	63 TO 64
7	65 TO 66	73	65 TO 66
4	67 TO 68	71	67 TO 68
0	69 TO 70	71	69 TO 70
6	71 TO 72	71	71 TO 72
8	73 TO 74	69	73 TO 74

0	75 TO 76	68	75 TO 76
6	77 TO 78	68	77 TO 78
7	79 TO 80	67	79 TO 80
6	81 TO 82	65	81 TO 82
0	83 TO 84	64	83 TO 84
4	85 TO 86	64	85 TO 86
6	87 TO 88	63	87 TO 88
3	89 TO 90	62	89 TO 90
0	91 TO 92	62	91 TO 92
2	93 TO 94	62	93 TO 94
3	95 TO 96	61	95 TO 96
0	97 TO 98	61	97 TO 98
5	99 TO 100	61	99 TO 100
5	101 TO 102	60	101 TO 102
3	103 TO 104	59	103 TO 104
0	105 TO 106	58	105 TO 106
6	107 TO 108	58	107 TO 108
3	109 TO 110	57	109 TO 110
4	111 TO 112	56	111 TO 112
0	113 TO 114	56	113 TO 114
3	115 TO 116	56	115 TO 116
1	117 TO 118	55	117 TO 118
0	119 TO 120	55	119 TO 120
6	121 TO 122	55	121 TO 122
3	123 TO 124	54	123 TO 124
3	125 TO 126	53	125 TO 126
0	127 TO 128	52	127 TO 128
0	129 TO 130	52	129 TO 130
2	131 TO 132	52	131 TO 132
0	133 TO 134	52	133 TO 134
0	135 TO 136	52	135 TO 136
2	137 TO 138	52	137 TO 138
0	139 TO 140	52	139 TO 140
0	141 TO 142	52	141 TO 142
4	143 TO 144	52	143 TO 144
0	145 TO 146	51	145 TO 146
2	147 TO 148	51	147 TO 148
0	149 TO 150	50	149 TO 150
0	151 TO 152	50	151 TO 152
4	153 TO 154	50	153 TO 154
0	155 TO 156	50	155 TO 156
0	157 TO 158	50	157 TO 158
5	159 TO 160	50	159 TO 160
0	161 TO 162	49	161 TO 162
0	163 TO 164	49	163 TO 164
5	165 TO 166	49	165 TO 166
0	167 TO 168	48	167 TO 168
2	169 TO 170	48	169 TO 170
0	171 TO 172	47	171 TO 172
0	173 TO 174	47	173 TO 174
2	175 TO 176	47	175 TO 176
0	177 TO 178	47	177 TO 178
0	179 TO 180	47	179 TO 180
4	181 TO 182	47	181 TO 182
0	183 TO 184	46	183 TO 184
0	185 TO 186	46	185 TO 186
2	187 TO 188	46	187 TO 188
0	189 TO 190	46	189 TO 190
3	191 TO 192	46	191 TO 192
0	193 TO 194	45	193 TO 194
0	195 TO 196	45	195 TO 196
6	197 TO 198	45	197 TO 198
0	199 TO 200	44	199 TO 200
0	201 TO 202	44	201 TO 202
225	203 TO	44	203 TO

MEAN = 130.6 STANDARD DEVIATION = 74.7 (57.2%)

SHIRLEY ROAD: CARS ONLY WITH BUS LANE

VARIATION OF QUEUE LENGTH WITH TIME (% OF SIMULATION PERIOD)

FOR BUS LANE LINK LINK NO. 5 LINK LENGTH = 836M

ALL VEHICLES		RIGHT TURNERS		FILTER VEHICLES	
MEAN LENGTH(M)	TIME	MEAN LENGTH(M)	TIME	MEAN LENGTH(M)	TIME
24	0 TO 10	0	0 TO 10	0	0 TO 10
38	11 TO 20	0	11 TO 20	0	11 TO 20
56	21 TO 30	0	21 TO 30	0	21 TO 30
96	31 TO 40	0	31 TO 40	0	31 TO 40
126	41 TO 50	0	41 TO 50	0	41 TO 50
195	51 TO 60	0	51 TO 60	0	51 TO 60
302	61 TO 70	0	61 TO 70	0	61 TO 70
368	71 TO 80	0	71 TO 80	0	71 TO 80
304	81 TO 90	0	81 TO 90	0	81 TO 90
364	91 TO	0	91 TO	0	91 TO

MEAN = 187.3 MEAN = 0.0 MEAN = 0.0

---------------------0000-------------------

SHIRLEY ROAD: CARS ONLY WITH BUS LANE

VEHICLE TRAVEL TIMES FOR NETWORK (IN SECONDS)
==

		CUMULATIVE DISTRIBUTION (AS A PERCENTAGE)	
COUNT	RANGE	COUNT	RANGE
0	20 TO 40	100	20 TO 40
0	41 TO 60	100	41 TO 60
0	61 TO 80	100	61 TO 80
13	81 TO 100	100	81 TO 100
36	101 TO 120	99	101 TO 120
55	121 TO 140	96	121 TO 140
93	141 TO 160	92	141 TO 160
91	161 TO 180	85	161 TO 180
105	181 TO 200	79	181 TO 200
100	201 TO 220	71	201 TO 220
79	221 TO 240	63	221 TO 240
62	241 TO 260	58	241 TO 260
67	261 TO 280	53	261 TO 280
76	281 TO 300	48	281 TO 300
73	301 TO 320	42	301 TO 320
78	321 TO 340	37	321 TO 340
94	341 TO 360	31	341 TO 360
76	361 TO 380	24	361 TO 380
85	381 TO 400	19	381 TO 400
86	401 TO 420	12	401 TO 420
81	421 TO	6	421 TO

MEAN = 273.4 STANDARD DEVIATION = 96.6 (35.4%)

SHIRLEY ROAD: CARS ONLY WITH BUS LANE

MEAN TRAVEL TIMES ACROSS THE NETWORK (IN SECONDS)

ORIGIN	DESTINATION 1	2	3	4
1	0	0	274	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0

SUMMARY OF MEAN LINK TIMES (IN SECONDS)

LINK	1	2	3	4	5	6	7	8	9	10
TIME	23	0	0	0	222	0	0	0	29	0

CROSS-CORDON TRAVEL IN VEHICLE-HOURS PER HOUR

ORIGIN	DESTINATION 1	2	3	4	TOTAL
1	0.0	0.0	76.2	0.0	76.2
2	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0
TOTAL	0.0	0.0	76.2	0.0	76.2

SHIRLEY ROAD: CARS ONLY WITH BUS LANE

VEHICLE TRAVEL TIMES FOR APPROACH LINK LINK NO. 1 (IN SECONDS)

COUNT	RANGE	CUMULATIVE DISTRIBUTION (AS A PERCENTAGE) COUNT	RANGE
0	0 TO 5	100	0 TO 5
0	6 TO 10	100	6 TO 10
53	11 TO 15	100	11 TO 15
333	16 TO 20	96	16 TO 20
606	21 TO 25	73	21 TO 25

367	26 TO 30	31	26 TO 30
65	31 TO 35	5	31 TO 35
7	36 TO 40	0	36 TO 40
0	41 TO	0	41 TO

MEAN = 22.8 STANDARD DEVIATION = 4.6 (20.4%)

SHIRLEY ROAD: CARS ONLY WITH BUS LANE

VEHICLE TRAVEL TIMES FOR BUS LANE LINK LINK NO. 5 (IN SECONDS)

		CUMULATIVE DISTRIBUTION (AS A PERCENTAGE)	
COUNT	RANGE	COUNT	RANGE
0	0 TO 5	100	0 TO 5
0	6 TO 10	100	6 TO 10
0	11 TO 15	100	11 TO 15
0	16 TO 20	100	16 TO 20
0	21 TO 25	100	21 TO 25
0	26 TO 30	100	26 TO 30
0	31 TO 35	100	31 TO 35
1	36 TO 40	100	36 TO 40
3	41 TO 45	100	41 TO 45
11	46 TO 50	100	46 TO 50
10	51 TO 55	99	51 TO 55
10	56 TO 60	98	56 TO 60
8	61 TO 65	97	61 TO 65
6	66 TO 70	97	66 TO 70
13	71 TO 75	96	71 TO 75
17	76 TO 80	95	76 TO 80
8	81 TO 85	94	81 TO 85
16	86 TO 90	94	86 TO 90
32	91 TO 95	92	91 TO 95
24	96 TO 100	90	96 TO 100
24	101 TO 105	88	101 TO 105
32	106 TO 110	86	106 TO 110
21	111 TO 115	84	111 TO 115
21	116 TO 120	83	116 TO 120
18	121 TO 125	81	121 TO 125
24	126 TO 130	80	126 TO 130
24	131 TO 135	78	131 TO 135
21	136 TO 140	76	136 TO 140
36	141 TO 145	75	141 TO 145
27	146 TO 150	72	146 TO 150
22	151 TO 155	70	151 TO 155
19	156 TO 160	68	156 TO 160
28	161 TO 165	67	161 TO 165
25	166 TO 170	65	166 TO 170
20	171 TO 175	63	171 TO 175
17	176 TO 180	61	176 TO 180
19	181 TO 185	60	181 TO 185
17	186 TO 190	59	186 TO 190
13	191 TO 195	58	191 TO 195
22	196 TO 200	57	196 TO 200
16	201 TO 205	55	201 TO 205
21	206 TO 210	54	206 TO 210
13	211 TO 215	52	211 TO 215
19	216 TO 220	51	216 TO 220
17	221 TO 225	50	221 TO 225
15	226 TO 230	49	226 TO 230

16	231	TO	235	47	231	TO	235
19	236	TO	240	46	236	TO	240
21	241	TO	245	45	241	TO	245
24	246	TO	250	43	246	TO	250
14	251	TO	255	42	251	TO	255
17	256	TO	260	40	256	TO	260
21	261	TO	265	39	261	TO	265
13	266	TO	270	38	266	TO	270
26	271	TO	275	37	271	TO	275
15	276	TO	280	35	276	TO	280
17	281	TO	285	34	281	TO	285
24	286	TO	290	32	286	TO	290
19	291	TO	295	31	291	TO	295
17	296	TO	300	29	296	TO	300
30	301	TO	305	28	301	TO	305
25	306	TO	310	26	306	TO	310
16	311	TO	315	24	311	TO	315
21	316	TO	320	23	316	TO	320
17	321	TO	325	21	321	TO	325
26	326	TO	330	20	326	TO	330
30	331	TO	335	18	331	TO	335
24	336	TO	340	16	336	TO	340
23	341	TO	345	14	341	TO	345
18	346	TO	350	12	346	TO	350
23	351	TO	355	11	351	TO	355
14	356	TO	360	9	356	TO	360
21	361	TO	365	8	361	TO	365
17	366	TO	370	7	366	TO	370
21	371	TO	375	5	371	TO	375
12	376	TO	380	4	376	TO	380
8	381	TO	385	3	381	TO	385
4	386	TO	390	2	386	TO	390
10	391	TO	395	2	391	TO	395
7	396	TO	400	1	396	TO	400
2	401	TO	405	1	401	TO	405
2	406	TO	410	1	406	TO	410
3	411	TO	415	1	411	TO	415
1	416	TO	420	0	416	TO	420
0	421	TO	425	0	421	TO	425
0	426	TO	430	0	426	TO	430
1	431	TO	435	0	431	TO	435
1	436	TO	440	0	436	TO	440
0	441	TO	445	0	441	TO	445
0	446	TO	450	0	446	TO	450
0	451	TO	455	0	451	TO	455
0	456	TO	460	0	456	TO	460
0	461	TO	465	0	461	TO	465
0	466	TO	470	0	466	TO	470
0	471	TO	475	0	471	TO	475
0	476	TO	480	0	476	TO	480
1	481	TO	485	0	481	TO	485
0	486	TO		0	486	TO	

MEAN = 222.0 STANDARD DEVIATION = 97.2 (43.8%)

SHIRLEY ROAD: CARS ONLY WITH BUS LANE

AVERAGE TRIP MATRIX

DESTINATION

ORIGIN

	1	2	3	4	TOTAL
1	0	0	1001	0	1001
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
TOTAL	0	0	1001	0	1001

SUMMARY OF FLOWS LEAVING LINKS
==============================

LINK	1	2	3	4	5	6	7	8	9	10
LEFT	0	0	0	0	0	0	0	0	0	0
STRT	1010	0	0	0	954	0	0	0	953	0
RIGHT	0	0	0	0	0	0	0	0	0	0
VPH	1010	0	0	0	954	0	0	0	953	0

SUMMARY OF FLOWS ENTERING LINKS
===============================

LINK	1	2	3	4	5	6	7	8	9	10
VPH	1016	0	0	0	1010	0	0	0	954	0

SUMMARY OF FUEL CONSUMPTION PER LINK
====================================

LINK	1	2	3	4	5	6	7	8	9	10
L/HR	32	0	0	0	167	0	0	0	29	0

TOTAL FUEL CONSUMPTION = 228 LITRES/HOUR

SHIRLEY ROAD: CARS ONLY WITH BUS LANE

CROSS-CORDON TRAVEL IN VEHICLE-KILOMETRES PER HOUR
==

DESTINATION

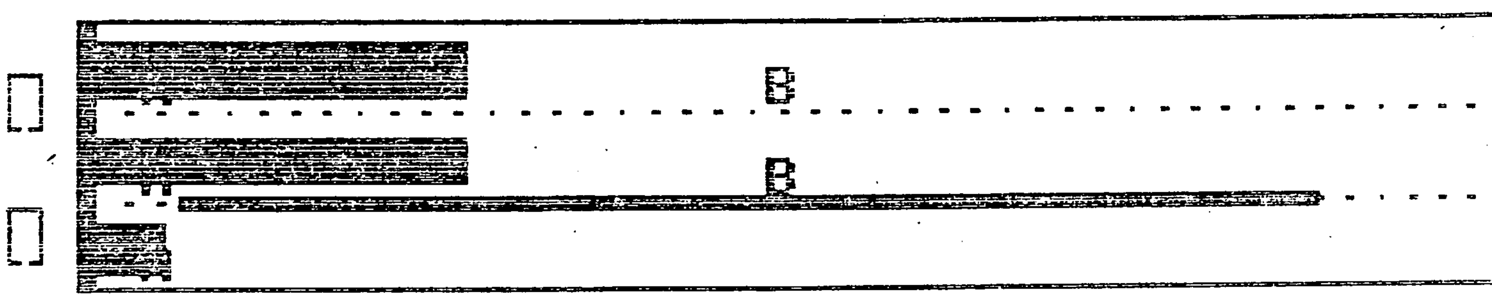
ORIGIN

	1	2	3	4	TOTAL
1	0.0	0.0	1437.4	0.0	1437.4
2	0.0	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0
4	0.0	0.0	0.0	0.0	0.0
TOTAL	0.0	0.0	1437.4	0.0	1437.4

FIGURE B2 : BLAMP MODELLING OF SITE 18 AND DATA INPUTS IN 'USER' MENU

BUS LANE MODEL | SITE 18

```
Setback (m)          =37
Cycle time (secs)    =120
Green time (secs)    =87
Bus flow (pcu's)     =58
Bus lane length(m)   =482
Link length (m)      =600
Total flow (pcu's)   =2448
No of lanes          =3
Flow profile int     =15
  No. of intervals   =11
    Interval 11       3100
```



Av.veh.delay	
Cars	Buses
56 secs	14 secs

```
Queues (m)
Bus A= 32
Bus C= 0
Car A= 33
Car B= 118
Car C= 0
```

```
Cycle
 11
Mins
 02
Secs
 35
```

FIGURE B3 : BLAMP MODELLING OF SITE 18 AND DATA INPUTS IN 'EXPERT' MENU

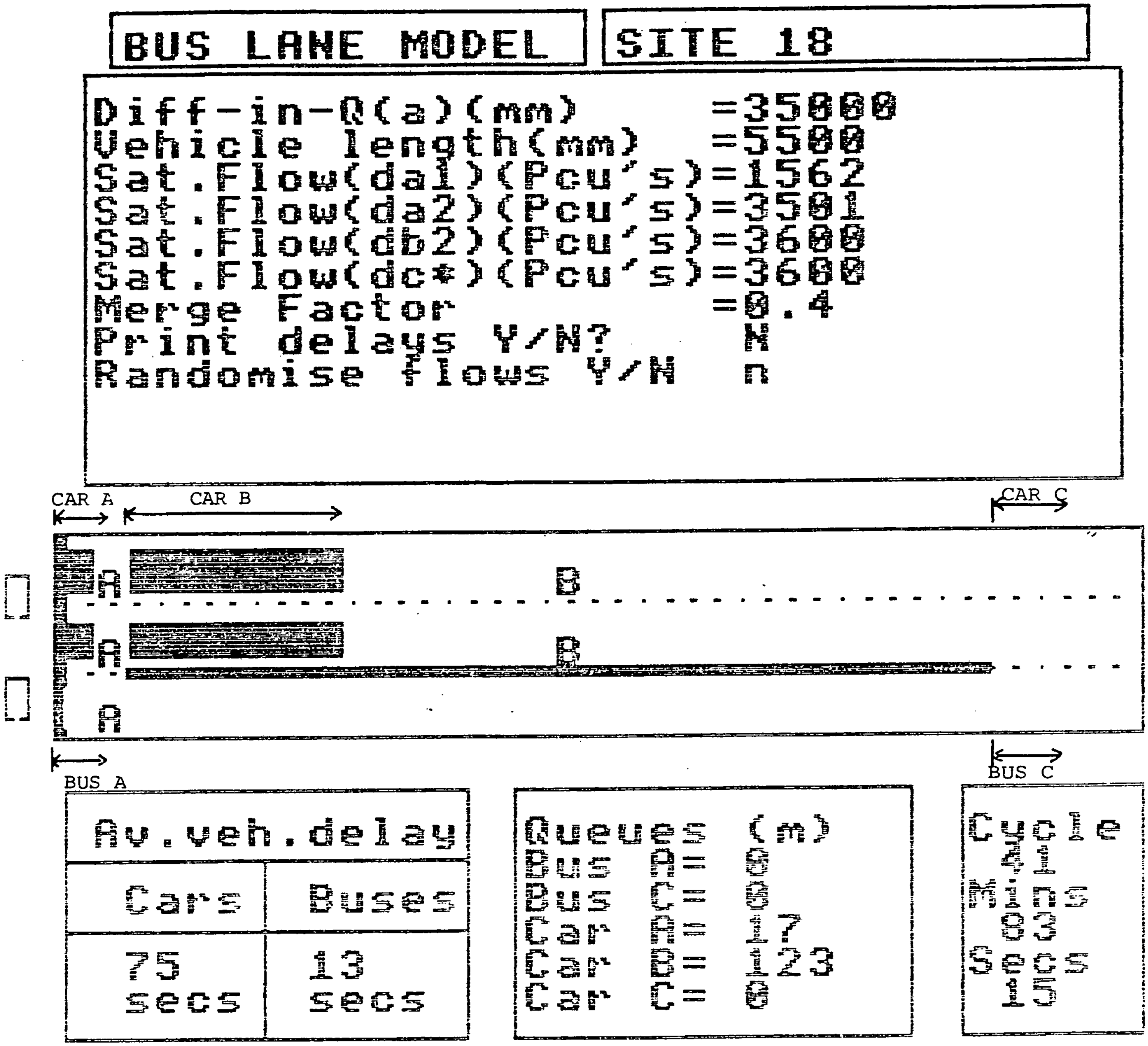
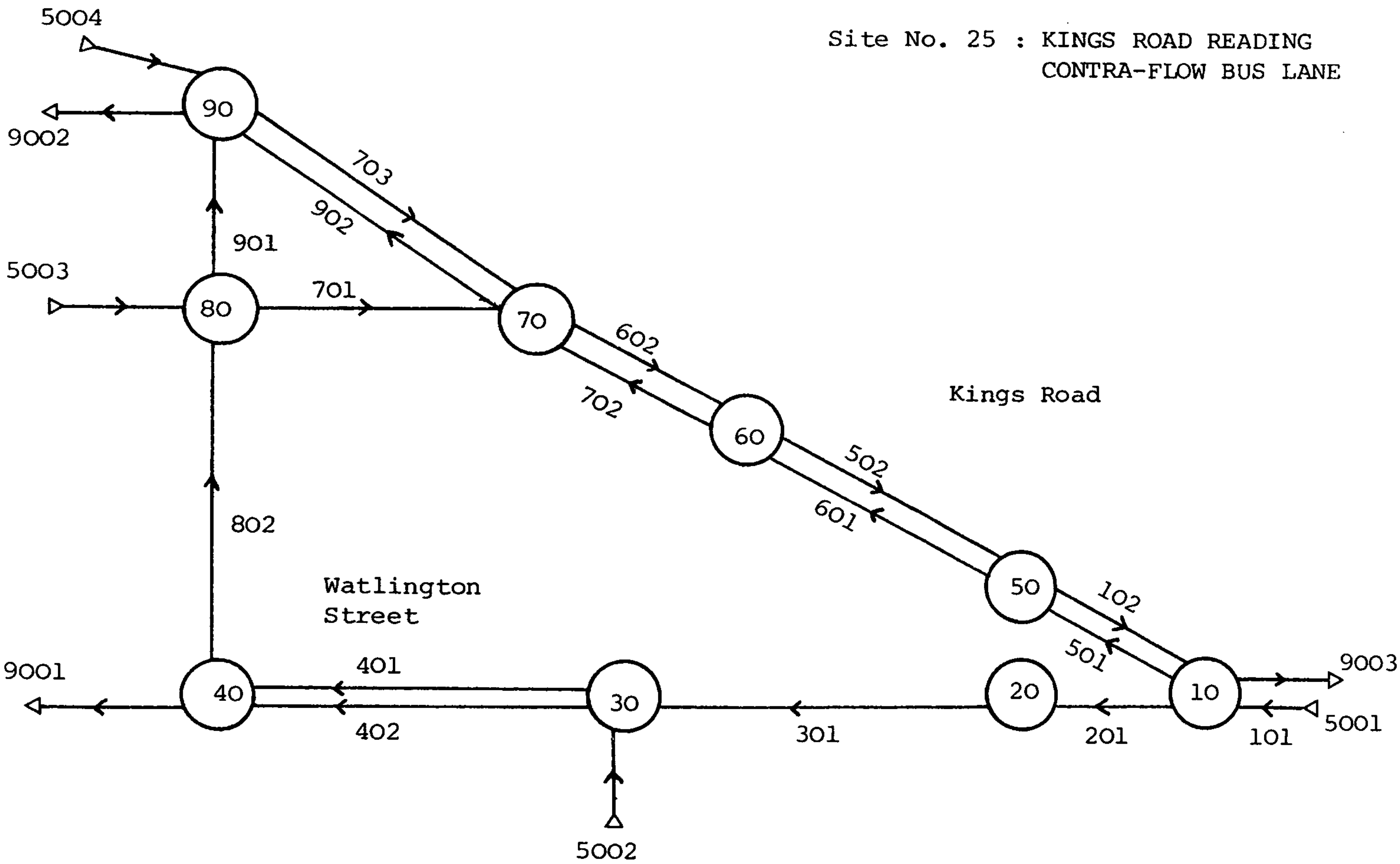


FIGURE B4 : EXAMPLE OF CONTRAM CODING/OUTPUT

Site No. 25 : KINGS ROAD READING
CONTRA-FLOW BUS LANE



CONTRA-FLOW LANE = LINKS 501, 601, 702 and 902

Signal controlled junctions = 30, 40, 70, 80, 90

Pelican crossings = 20, 50, 60

Uncontrolled junctions = 10

Notes 1. See Appendix A for further details of the site.
2. Other links not modelled were considered to be of secondary importance.

CONTRAM OUTPUT FOR SITE 25

NETWORK AND TIME DATA   WITH BUS LANE

CARD TYPE	TIME UNIT (SECS)	TIME INTERVAL BOUNDARIES FOR SIMULATION PERIOD. (HOURS AND MINUTES) INTERVAL NUMBER : 1	2	3	4	5	6	7	8	9	10	11	12	13
1	1	715	730	745	800	815	830	845	900	915	930	1030	0	0

0

CARD TYPE	ORIGIN NUMBER	FEEDS UP TO 5 LINKS : (LETTERS DENOTE BANNED MOVEMENTS)				
3	5001	101	0	0	0	0
3	5002	302	0	0	0	0
3	5003	801	0	0	0	0
3	5004	903	0	0	0	0

CARD TYPE	FREE LINK NUMBER	FEEDS UP TO 5 LINKS OR DESTINATIONS : (LETTERS DENOTE BANNED MOVEMENTS)					CRUISE TIME (SECS)	LENGTH (METRS)	SAT,N FLOW (PCU/H)	STORE CAP. (PCUS)	JUNCTION NUMBER
4	101	201B	501C	0	0	0	42	500	3600	182	10
4	102	9003	0	0	0	0	6	75	3600	27	10

CARD TYPE	SIGNL,D LINK NUMBER	FEEDS UP TO 5 LINKS OR DESTINATIONS : (LETTERS DENOTE BANNED MOVEMENTS)					CRUISE TIME (SECS)	LENGTH (METRS)	SAT,N FLOW (PCU/H)	STORE CAP. (PCUS)	SIGNAL /JUNCT NUMBER	STAGE WHEN GREEN	STAGE GREEN %	LINK DELAY %
6	201	301B	0	0	0	0	4	50	5400	27	20	1	100	100
6	301	401B	402B	0	0	0	45	540	6000	295	30	1	100	100
6	302	401	402	0	0	0	42	500	3600	182	30	2	100	100
6	401	802B	0	0	0	0	12	145	1800	26	40	1	100	100
6	402	9001	0	0	0	0	12	145	3600	53	40	1	100	100
6	501	601C	0	0	0	0	6	75	1800	14	50	1	100	100
6	502	102	0	0	0	0	23	275	3600	100	50	1	100	100
6	601	702C	0	0	0	0	23	275	1800	50	60	1	100	100
6	602	502	0	0	0	0	28	330	3600	120	60	1	100	100
6	702	902C	0	0	0	0	28	330	1800	60	70	1	100	100
6	703	602	0	0	0	0	21	250	3600	91	70	1	100	100
6	701	602	0	0	0	0	13	160	3600	58	70	2	100	100
6	801	701	901	0	0	0	42	500	4100	182	80	1	100	100
6	802	701B	901B	0	0	0	23	280	3600	102	80	2	100	100
6	901	9002B	0	0	0	0	13	150	3400	55	90	1	100	100
6	902	9002C	0	0	0	0	21	250	3600	91	90	2	100	100
6	903	703	0	0	0	0	42	500	3600	182	90	2	100	100

CARD TYPE	SIGNAL NUMBER	LOST TIME (SECS)
7	20	10
7	30	10
7	40	10
7	50	10
7	60	10
7	70	10
7	80	10
7	90	10

CARD TYPE	PCUS PER CLASS CAR	B	L	CRUISE TIMES(% CAR VALUE) CAR	B	L
9	1.0	2.0	0.0	100	100	0

CARD TYPE NO.	VEH CLASS	FUEL COEFFICIENTS DISTANCE A	B	C	DELAY A	B	C
10	C	164	240	200	150	107	340
10	B	492	720	600	450	321	1020

2 UNCONTROLLED LINKS
0 GIVE-WAY LINKS
17 SIGNALIZED LINKS
19 LINKS IN ALL

DESTINATIONS DEDUCED FROM LINK DATA:-
9003 9001 9002

TRAFFIC DEMANDS

SITE 25AM1 WITH BUS LANE 05 10 85

ORIG NO.	DEST NO.	PKT SIZE (VEH)	LIN. DIST (MTR)	ENTRY FLOW-RATE IN TIME INTERVALS (VEH/HR) : 1	2	3	4	5	6	7	8	9	10	11	12	13
5001	9001	4C		1817	1817	1560	1652	1744	1728	1411	1500	0	0			
5001	9002	4C		779	779	668	708	748	740	604	600	0	0			
5001	9002	1B		32	32	32	40	24	48	44	50	0	0			
5002	9001	4C		355	355	324	356	452	460	122	200	0	0			
5002	9002	4C		525	525	532	664	420	452	384	400	0	0			
5003	9002	4C		200	200	384	400	332	296	280	300	0	0			
5003	9003	4C		1264	1264	1104	1284	1008	1386	1000	1000	0	0			
5004	9003	4C		1072	1072	900	1156	864	1236	900	1000	0	0			

TOTAL VEHICLE FLOW RATES FROM EACH ORIGIN (VEH/HR)

ORIGINS	FLOWS									
5001	2628	2628	2260	2400	2516	2516	2059	2150	0	0
5002	880	880	856	1020	872	912	506	600	0	0
5003	1464	1464	1488	1684	1340	1682	1280	1300	0	0
5004	1072	1072	900	1156	864	1236	900	1000	0	0

TOTAL VEHICLE FLOW RATES DIRECTED TOWARDS EACH DESTINATION (VEH/HR)

DESTINATIONS	FLOWS									
9003	2336	2336	2004	2440	1872	2622	1900	2000	0	0
9001	2172	2172	1884	2008	2196	2188	1533	1700	0	0
9002	1536	1536	1616	1812	1524	1536	1312	1350	0	0

TOTAL VEHICLE FLOW RATES ENTERING THE NETWORK (VEH/HR)

6044	6044	5504	6260	5592	6346	4745	5050	0	0

CONTROL DATA

CONTROL DATA SITE 25AM1 WITH BUS LANE 05 10 85

CARD
TYPE
NO.

50 NUMBER OF ITERATIONS = 1

52 CONVERGENCE MONITOR PRINTED FOR LAST ITERATION

53 LINK-BY-LINK DATA (ALL PARAMETERS) PRINTED FOR LAST ITERATION

54 LINK-BY-LINK VALUES (FLOWS,QUEUES,QUEUE TIMES,AVERAGE SPEEDS) PRINTED FOR LAST ITERATION

55 MEASURE OF FAIRNESS (SPEEDS) PRINTED FOR LAST ITERATION

56 TURNING MOVEMENTS PRINTED FOR LAST ITERATION

ALL LINKS

	SIGNAL PLAN NO.	PLAN TYPE	CYCLE TIME (SEC)	STAGE 1 GREEN (SEC)	STAGE 2 GREEN (SEC)	STAGE 3 GREEN (SEC)	STAGE 4 GREEN (SEC)
71	1	FIXED CYCLE & FIXED SPLITS	100	88	0	0	0
71	2	FIXED CYCLE & FIXED SPLITS	80	28	33	0	0
71	3	FIXED CYCLE & FIXED SPLITS	67	33	19	0	0
71	4	FIXED CYCLE & FIXED SPLITS	67	57	0	0	0
71	5	FIXED CYCLE & FIXED SPLITS	67	24	30	0	0
71	6	FIXED CYCLE & FIXED SPLITS	67	30	24	0	0

SIGNAL NUMBER OF THE FIXED-TIME PLAN OPERATED IN TIME-INTERVAL :

	SIGNAL NO.	1	2	3	4	5	6	7	8	9	10	11	12	13
77	20	1	1	1	1	1	1	1	1	1	1			
77	30	3	3	3	3	3	3	3	3	3	3			
77	40	4	4	4	4	4	4	4	4	4	4			
77	50	1	1	1	1	1	1	1	1	1	1			
77	60	1	1	1	1	1	1	1	1	1	1			
77	70	2	2	2	2	2	2	2	2	2	2			
77	80	5	5	5	5	5	5	5	5	5	5			
77	90	6	6	6	6	6	6	6	6	6	6			

PACKET SIZE WITHIN EACH O-D MOVEMENT IS CONSTANT
THE TOTAL NUMBER OF PACKETS ENTERING THE NETWORK IS 2906
THE TOTAL NUMBER OF PCUS IS 11474

NETWORK AND TIME DATA

SITE 25AM1 WITH BUS LANE 05 10 85

CONTROL DATA SITE 25AM1 WITH BUS LANE 05 10 85

ITERATION NUMBER 1

TIME INTERVALS :

1	2	3	4	5	6	7	8	9	10
715 730	745	800	815	830	845	900	915	930	1030

TOTALS

JOURNEY-TIME (VEH-HRS)

														TOTALS
TRAVELLING	41.1	44.8	40.4	44.3	41.2	45.2	37.3	37.9	3.6	0.0	0.0	0.0	0.0	335.7
DELAYED	11.7	14.0	13.3	17.7	23.9	28.9	28.8	17.2	1.3	0.0	0.0	0.0	0.0	156.9
TOTAL	52.8	58.8	53.7	61.9	65.0	74.1	66.2	55.0	4.9	0.0	0.0	0.0	0.0	492.4

DISTANCE TRAVELLED (VEH-KMS)

													TOTALS
1771	1928	1739	1905	1773	1944	1607	1629	154	0	0	0	0	14450

OVERALL NETWORK SPEED (KM/HR)

33.5	32.8	32.4	30.8	27.3	26.2	24.3	29.6	31.7

TOTAL FINAL QUEUES (PCUS)

78	114	132	283	265	329	202	120	5

FUEL CONSUMPTION (LITRES)

														TOTALS
TRAVELLING	175	191	172	189	175	193	160	163	15	0	0	0	0	1433
DELAYED	30	36	34	46	62	75	75	45	3	0	0	0	0	406
TOTAL	205	227	207	235	237	268	235	207	19	0	0	0	0	1840

CONVERGENCE MONITOR - SUMMARIES OF JOURNEY-TIMES, DISTANCES AND QUEUES
FOR LAST FIVE ITERATIONS

NETWORK AND TIME DATA

SITE 25AM1 WITH BUS LANE 05 10 85

LINK-BY-LINK DATA - ALL PARAMETERS - FOR TRAFFIC AND ECONOMIC ASSESSMENTS RUN ON 29-3

NETWORK AND TIME DATA WITH BUS LANE
SITE 25AM1 WITH BUS LANE 05 10 85
CONTROL DATA SITE 25AM1 WITH BUS LANE 05 10 85

TIME INTERVAL 1 START 715 FINISH 730 ITERATION NUMBER 1

LINK NO. AND TYPE	INIT. QUEUE (PCU)	VEHICLE ARRIVALS (VEH) C	B	L	DEPART FROM QUEUE (PCU)	FINAL QUEUE (PCU)	SPARE THRU-PUT CAPTY (PCU)	LINK STORE LEFT	DEG. OF SAT. (%)	AV. QUEUE TIME (SEC)	TOTAL TIME SPENT (VEH-HRS) C	B	L	TOTAL TRAVEL DISTANCE (VEH-KM) C	B	L	AV. JOURNEY SPEED (KM/H)	JUNCT. NO.	PLAN	CYCLE TIME (SEC)	GREEN TIME (SEC)
101U	0	616	8		632	0	268	182	70	0	7.4	.1		317	4		43	10		0	0
102U	0	472			472	0	428	27	52	0	.8			36			45	10		0	0
201S	0	616			615	1	573	26	51	0	.8			31			45	20	FCFS	100	88
301S	0	584			573	11	165	284	79	8	9.3			322			37	30	FCFS	67	33
302S	0	208			201	7	53	175	81	17	3.7			107			31	30	FCFS	67	19
401S	0	288			286	2	96	24	75	3	1.1			42			35	40	FCFS	67	57
402S	0	472			470	2	295	51	61	1	1.8			69			40	40	FCFS	67	57
501S	0		8		16	0	380	14	4	0		.0			1		45	50	FCFS	100	88
502S	0	480			478	2	314	98	60	1	3.3			134			41	50	FCFS	100	88
601S	0		7		14	0	382	50	3	0		.0			2		43	60	FCFS	100	88
602S	0	492			490	2	302	118	62	1	4.1			166			41	60	FCFS	100	88
701S	0	284			277	7	93	51	76	13	2.4			45			22	70	FCFS	80	33
702S	0		7		14	0	143	60	8	16		.1			2		27	70	FCFS	80	28
703S	0	244			236	8	79	83	77	16	2.7			61			24	70	FCFS	80	28
801S	0	348			333	15	33	167	95*	19	5.9			176			30	80	FCFS	67	24
802S	0	280			274	6	128	96	69	10	2.7			79			31	80	FCFS	67	30
901S	0	312			304	8	75	47	82	10	2.3			47			23	90	FCFS	67	30
902S	0		7		14	0	308	91	4	13		.0			2		26	90	FCFS	67	24
903S	0	256			249	7	73	175	79	13	4.2			130			33	90	FCFS	67	24

LINK-BY-LINK VALUES - ARRIVAL FLOWS (PCU/HR)

NETWORK AND TIME DATA WITH BUS LANE
SITE 25AM1 WITH BUS LANE 05 10 85
CONTROL DATA SITE 25AM1 WITH BUS LANE 05 10 85

ITERATION NUMBER 1

TIME INTERVALS :

LINK NO.& TYPE	1	2	3	4	5	6	7	8	9	10				TIME INTERVAL WITH MAX. FLOWS
	715	730	745	800	815	830	845	900	915	930	1030			
101U	2528	2672	2304	2432	2544	2552	2120	2216	96	0	0	0	0	2
102U	1888	2336	2080	2288	1968	2384	2096	2064	416	0	0	0	0	6
201S	2464	2592	2256	2352	2496	2464	2032	2112	96	0	0	0	0	2
301S	2336	2592	2272	2352	2464	2480	2048	2112	208	0	0	0	0	2
302S	832	880	864	1008*	880*	928*	512	592	32	0	0	0	0	4
401S	1152	1312	1216	1328	1200	1184	1024	1008	112	0	0	0	0	4
402S	1888	2176	1936	1968	2176	2208	1616	1680	208	0	0	0	0	6
501S	64	64	64	72	56	88	88	104	0	0	0	0	0	8
502S	1920	2304	2080	2304	1968	2384	2096	2064	400	0	0	0	0	6
601S	56	64	64	80	56	88	88	96	8	0	0	0	0	8
602S	1968	2320	2080	2288	1952	2416	2080	2048	368	0	0	0	0	6
701S	1136	1248	1120	1184	1024	1248	1120	1072	160	0	0	0	0	2
702S	56	64	64	80	48	96	88	96	8	0	0	0	0	6
703S	976	1072	912	1120*	912	1184*	944	992	96	0	0	0	0	6
801S	1392*	1456*	1504*	1680&	1344&	1664&	1312*	1296*	48	0	0	0	0	4
802S	1120	1280	1232	1328&	1200&	1200&	1024R	1008	144	0	0	0	0	4
901S	1248	1488*	1584*	1664*	1536*	1456*	1424*	1280*	240	0	0	0	0	4
902S	56	64	64	80	48	88	88	104	8	0	0	0	0	8
903S	1024	1072	912	1136*	880	1216*	912	1008	48	0	0	0	0	6

NOTE: R = REDUCED CAPACITY
* = DEG. OF SAT. OVER 90%
& = BOTH R AND *

NUMBERS OF PCUS ENTERING AND LEAVING THE NETWORK IN EACH TIME INTERVAL

ENTERING	1520	1516	1388	1572	1408	1596	1206	1268	0	0
LEAVING	1262	1508	1404	1496	1432	1534	1310	1310	218	0

LINK-BY-LINK VALUES - FINAL QUEUES (PCUS)

NETWORK AND TIME DATA WITH BUS LANE
SITE 25AM1 WITH BUS LANE 05 10 85
CONTROL DATA SITE 25AM1 WITH BUS LANE 05 10 85

ITERATION NUMBER 1

TIME INTERVALS :

715 730 745 800 815 830 845 900 915 930 1030

LINK NO.& TYPE	1	2	3	4	5	6	7	8	9	10				TIME INTERVAL WITH MAX. FINAL QUEUE
101U	0	0	0	0	0	0	0	0	0	0	0	0	0	0
102U	0	0	0	0	0	0	0	0	0	0	0	0	0	0
201S	1	1	1	1	1	1	1	1	0	0	0	0	0	1
301S	11	15	11	11	12	13	8	9	1	0	0	0	0	2
302S	7	9	8	18	10	11	3	3	0	0	0	0	0	4
401S	2	4	3	4	3	3	2	1	0	0	0	0	0	2
402S	2	2	2	2	2	2	1	1	0	0	0	0	0	1
501S	0	0	0	0	0	0	0	0	0	0	0	0	0	0
502S	2	2	2	2	2	2	2	2	0	0	0	0	0	1
601S	0	0	0	0	0	0	0	0	0	0	0	0	0	0
602S	2	2	2	2	2	2	2	2	0	0	0	0	0	1
701S	7	10	7	9	7	10	7	7	1	0	0	0	0	2
702S	0	0	0	0	0	0	0	0	0	0	0	0	0	0
703S	8	10	7	12	7	14	7	9	0	0	0	0	0	[illegible]
801S	15	24	37	96	90	140	104	64	[illegible]	0	0	0	0	[illegible]
802S	5	8	7	39	41	46	7	5	0	0	0	0	0	6
901S	9	19	39	77F	83F	71F	52	10	1	0	0	0	0	5
902S	0	0	0	0	0	0	0	0	0	0	0	0	0	0
903S	7	8	6	10	5	14	6	7	0	0	0	0	0	6
TOTALS	78	114	132	283	265	329	202	120	5	0				

LINK-BY-LINK VALUES - AVERAGE QUEUE TIMES (SECS)

NETWORK AND TIME DATA WITH BUS LANE
SITE 25AM1 WITH BUS LANE 05 10 85
CONTROL DATA SITE 25AM1 WITH BUS LANE 05 10 85

ITERATION NUMBER 1

TIME INTERVALS :

LINK NO.& TYPE	1	2	3	4	5	6	7	8	9	10				TIME INTERVAL WITH MAX. QUEUE TIME
	715	730	745	800	815	830	845	900	915	930	1030			
101U	0	0	0	0	0	0	0	0	0	0	0	0	0	0
102U	0	0	0	0	0	0	0	0	0	0	0	0	0	0
201S	0	1	1	1	1	1	1	1	0	0	0	0	0	2
301S	8	16	16	14	14	15	13	10	8	8	0	0	0	2
302S	17	30	31	47	51	38	26	17	17	17	0	0	0	5
401S	3	8	9	9	9	8	7	4	2	0	0	0	0	3
402S	1	2	2	2	2	2	2	1	1	0	0	0	0	2
501S	0	0	0	0	0	0	0	0	0	0	0	0	0	0
502S	1	2	2	2	2	2	2	2	1	0	0	0	0	2
601S	0	0	0	0	0	0	0	0	0	0	0	0	0	0
602S	1	2	2	2	2	2	2	2	1	0	0	0	0	2
701S	13	21	21	20	20	21	21	18	13	13	0	0	0	2
702S	16	16	16	16	16	16	16	16	16	16	0	0	0	1
703S	16	27	25	28	28	31	31	22	16	16	0	0	0	6
801S	19	49	76	167	244	284	301	207	82	13	0	0	0	7
802S	10	16	17	68	121	133	63	14	10	10	0	0	0	6
901S	10	33	70	138	191	184	147	74	14	10	0	0	0	5
902S	13	13	13	13	13	13	13	13	13	13	0	0	0	1
903S	13	22	20	23	22	27	29	19	13	13	0	0	0	7

LINK-BY-LINK VALUES - AVERAGE SPEED OF A CAR (KMS/HR)

NETWORK AND TIME DATA WITH BUS LANE
SITE 25AM1 WITH BUS LANE 05 10 85
CONTROL DATA SITE 25AM1 WITH BUS LANE 05 10 85

ITERATION NUMBER 1

TIME INTERVALS :

715 730 745 800 815 830 845 900 915 930 1030

LINK NO.& TYPE	1	2	3	4	5	6	7	8	9	10				TIME INTERVAL WITH MIN. AV. SPEED
101U	43	43	43	43	43	43	43	43	43	43	0	0	0	1
102U	45	45	45	45	45	45	45	45	45	45	0	0	0	1
201S	45	36	36	36	36	36	36	36	45	45	0	0	0	2
301S	37	32	32	33	33	32	34	35	37	37	0	0	0	2
302S	31	25	25	20	19	23	26	31	31	31	0	0	0	5
401S	35	26	25	25	25	26	27	33	37	44	0	0	0	3
402S	40	37	37	37	37	37	37	40	40	44	0	0	0	2
501S	45	45	45	45	45	45	45	45	45	45	0	0	0	1
502S	41	40	40	40	40	40	40	40	41	43	0	0	0	2
601S	43	43	43	43	43	43	43	43	43	43	0	0	0	1
602S	41	40	40	40	40	40	40	40	41	42	0	0	0	2
701S	22	17	17	17	17	17	17	19	22	22	0	0	0	2
702S	27	27	27	27	27	27	27	27	27	27	0	0	0	1
703S	24	19	20	18	18	17	17	21	24	24	0	0	0	6
801S	30	20	15	9	6	6	5	7	15	33	0	0	0	7
802S	31	26	25	11	7	6	12	27	31	31	0	0	0	6
901S	23	12	7	4	3	3	3	6	20	23	0	0	0	5
902S	26	26	26	26	26	26	26	26	26	26	0	0	0	1
903S	33	28	29	28	28	26	25	30	33	33	0	0	0	7

APPENDIX C

OTHER NON-MODELLING ANALYSIS METHODS

APPENDIX C

OTHER NON-MODELLING ANALYSIS METHODS

The method described in Section 6.2 for evaluating the effects of a with-flow bus lane without computer modelling applies to the situation where the bus lane does not reduce junction capacity. However, where junction capacity is reduced, it may still be possible to analyse the effect of this reduction without recourse to computer modelling, although associated effects such as blocking back and traffic diversions may be difficult to assess.

The methods available include the use of graphical techniques or mathematical expressions for the prediction of vehicular delay. The most appropriate formulae appear to be those based on time dependent queueing theory: 'steady state' theory, from which the relationships in TP56[16] were developed, predicts an infinite delay when demand reaches capacity, while deterministic theory predicts no delay until demand exceeds capacity, neither approach therefore being satisfactory over the range of conditions commonly found in practice. These methods are broadly compared in Figure C1 for the general queueing situation.

Graphical Techniques

The use of graphical techniques for assessing junction delay and queue lengths at signal controlled junctions is illustrated in the example in Figure C2. This technique is a simplification of reality as it does not take account of vehicle move-up times, but is commonly used in practice[3,10]. A 'queue profile' is constructed for a single cycle of the signal's operation, from a knowledge of:

- the arrival flow
- the discharge flow
- signal timings
- effective setback distance (for the 'with' bus lane case)

The area beneath the profile gives an estimate of total delay while the height of the profile relative to the x axis gives the position of the back of the queue. This approach assumes regular traffic arrivals and, with the element of randomness excluded, would be expected to underestimate delay to some extent. (Delays calculated in this way are actually the same as those predicted by the first term of the delay expression in TP56[16].) Such underestimation is likely to be small, however, and delay predictions have been found to be similar to those predicted by time dependent queueing theory for traffic intensities below about 0.85. (The graphical technique can be used for higher traffic intensities, but would have to be repeated for a series of short time intervals (perhaps even every cycle) the queue length at the end of a time interval being made equal to the queue at the beginning of the next. This would clearly be a time consuming procedure (more suitable for computer calculation).

For lower traffic intensities arrival flows would normally be taken to be constant within time intervals of, say, 15 minutes, and the delay would be assumed to be the same for each cycle within the interval. The procedure has then to be repeated for each time interval for which conditions vary.

In the example in Figure C2, in which only cars are considered, three profiles have been superimposed on each other:

(i) The 'without' bus lane profile
(ii) The 'with' bus lane profile for lane 1 (nearside lane)
(iii) The 'with' bus lane profile for lane 2 (offside lane)

For the 'without' bus lane situation the arrival rate is maintained throughout the cycle and all vehicles have discharged after some 64 seconds. Average delay per vehicle, d (secs), is given by:

$$d = \frac{c(1-\lambda)^2}{2(1-\lambda x)} \qquad \ldots\ldots \quad (1)$$

Where c = cycle time
λ = proportion of effective green time per cycle (g/c)
x = degree of saturation ($q/\lambda s$)
where q = arrival flow
s = discharge flow

In this example, d = 16.0 secs/veh

For the 'with' bus lane situation, vehicles in this example arrive equally in each lane until the setback is full (36 secs after the start of red) and all subsequent vehicles arrive and (are assumed to) depart from the offside lane. The arrival rate is not therefore constant in each lane throughout the cycle, and delay may be calculated from a consideration of the area of under profile, as given below:

Lane 1

Delay = (36x2) + (14x4) + (8x2) = 144 veh secs.
Arrival flow/cycle = 4 vehs
∴ Average delay per vehicle = 144/4 = 36 secs

Lane 2

Delay = 144 (as lane 1) + (22x4.5) = 243 veh secs.
Arrival flow/cycle = 18.2 vehs (i.e. total flow minus flow in Lane 1)
∴ Average delay per vehicle = 13.3 secs.

∴ Total delay for non-priority vehicles with the bus lane
= (144 + 243)/22.2 = 17.4 secs/veh.

∴ Disbenefit to non-priority vehicles = 17.4 - 16.0 = 1.4 secs/veh.

The delay to buses in the 'with' bus lane situation can be calculated from equation (1) above, considering the nearside lane profile in Figure C2 and calculating an appropriate average arrival flow, q (this is required as buses can arrive in lane 1 both when the setback is full and after it has cleared, in contrast to the assumption for non-priority vehicle arrivals in this lane given above). The appropriate value of q is that average value (called q^1) which gives a total delay equal to that calculated for the lane 1 'with' bus lane case.

This is calculated from:

Maximum queue per cycle (Q_m) = 144/0.5r = 5.8 vehicles
Time taken from start of red for 5.8 vehicles to discharge

$$= r + \frac{Q_m}{S} = 50 + \frac{5.8}{0.5} = 61.6 \text{ secs}$$

∴ Arrival flow, $q^1 = \frac{5.8}{61.6} = 0.094$ secs/veh

Substituting q^1 into equation (1) gives a delay to buses of 15.4 secs/veh.

The benefit to buses is therefore 16.0 - 15.4 secs
= 0.6 secs/veh.

This example applies to a layout where the traffic intensity is low (0.44) and no queue is left over at the end of the green period. These and other more complex situations can be analysed using similar techniques although computer modelling is likely to be preferred.

Time Dependent Queueing Formulae

Predictions of queue lengths and delay for non-priority traffic can be obtained from approximation methods related to time dependent queueing theory. The co-ordinate transformation method, described in Reference 25 is appropriate for the calculation of both queue length and delay. The formulae are reproduced below:

Queue Length, L $= \frac{1}{2}((A^2 + B)^{\frac{1}{2}} - A)$ vehs.

Where $A = \dfrac{(1-\rho)(\mu t)^2 + (1 - L_o)/\mu t - 2(1-C)(L_o + \rho\mu t)}{\mu t + (1 - C)}$

$B = \dfrac{4(L_o + \rho\mu t)[\mu t - (1-C)(L_o + \rho\mu t)]}{\mu t + (1 - C)}$

Where ρ = traffic intensity (i.e. demand (q)/capacity (μ))
t = time interval
L_o = number of vehicles queueing at the start of the interval
C = constant depending on arrival and service patterns
(For fixed time signals, $C \simeq 0.55$)

Delay/veh D $= \frac{1}{2}((J^2 + K)^{\frac{1}{2}} - J)$ secs

Where $J = \frac{t}{2}(1-\rho) - \frac{1}{\mu}(L_o - C + 2)$

$K = \frac{4}{\mu}\left[\frac{t}{2}(1-\rho) + \frac{\rho t C}{2} - \left(\frac{L_o + 1}{\mu}\right)(1 - C)\right]$

These formulae predict the queue length at the end of a time interval and the average delay per vehicle within the interval, calculations needing to be repeated for consecutive time intervals as demand flows vary. The estimation of the effect of a bus lane on queue length and delay requires adjustment of capacity (μ) in the above formulae as described in Figure 7.3 and in the accompanying text. The benefit of the bus lane to buses may be calculated as described in Section 7.1.1 and as illustrated in Appendix B.

FIGURE C1 : RELATIONSHIP BETWEEN DELAY AND TRAFFIC INTENSITY FOR DIFFERENT QUEUEING THEORIES

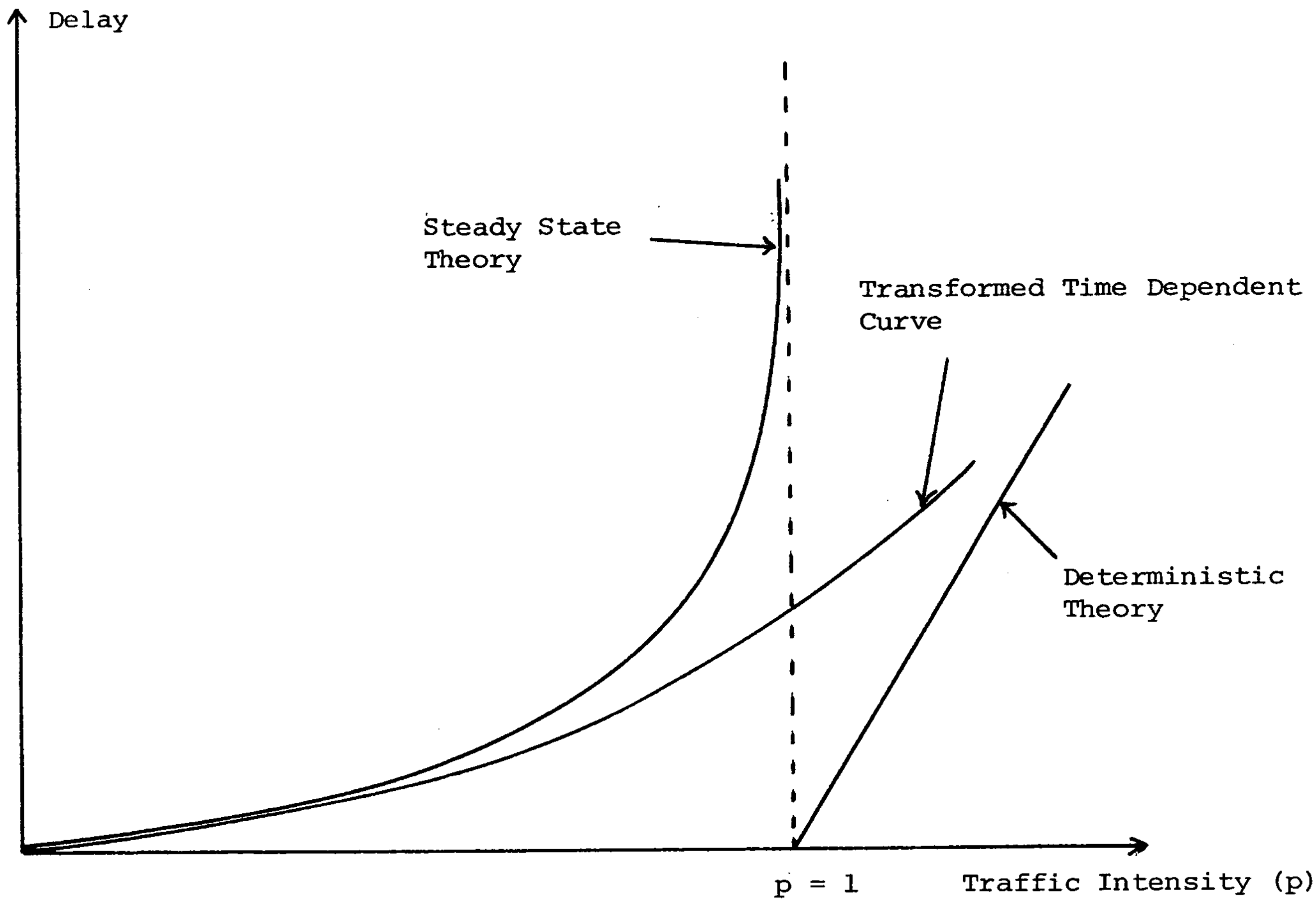
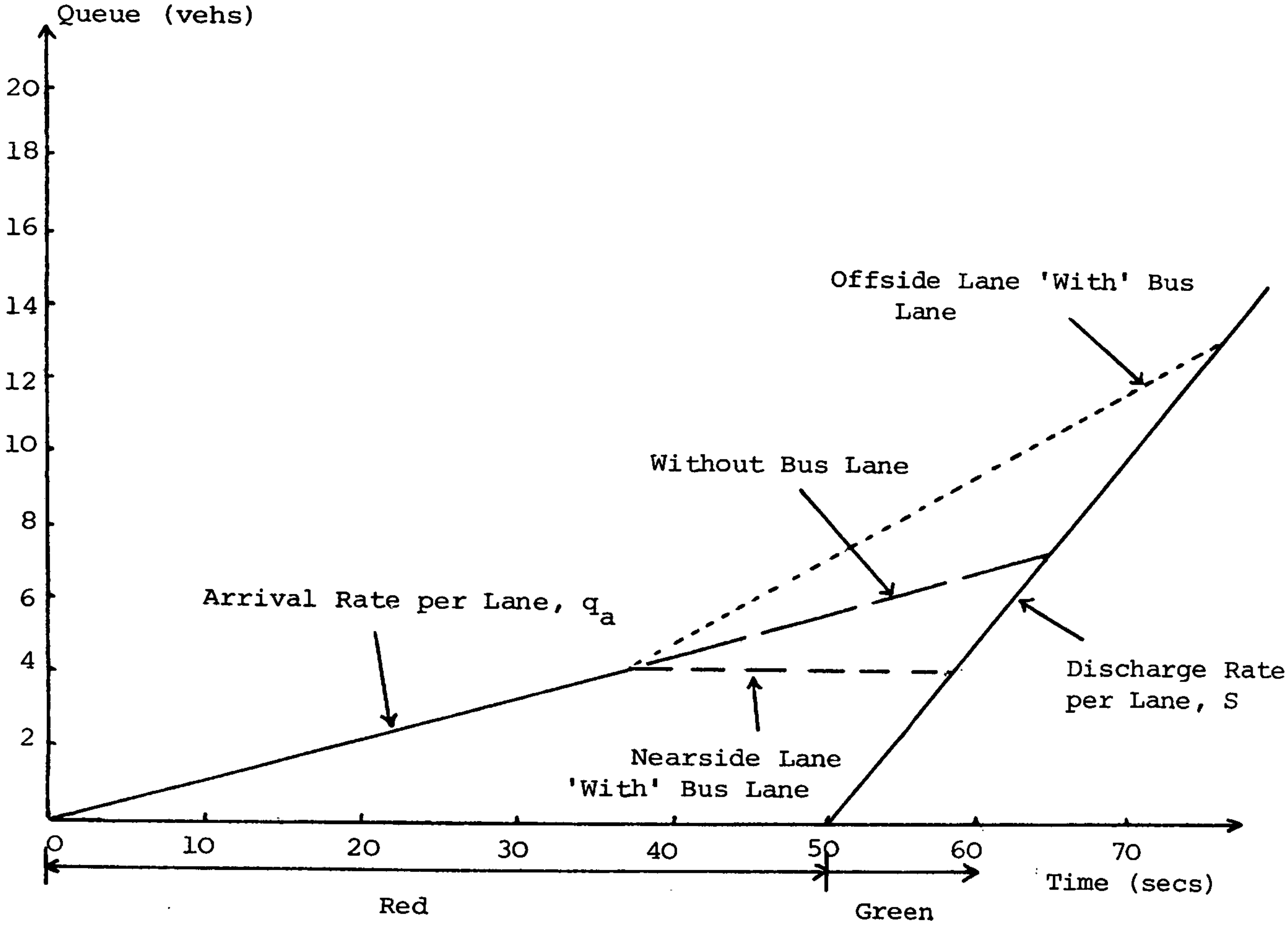


FIGURE C2 : EXAMPLE OF GRAPHICAL TECHNIQUE FOR ESTIMATING JUNCTION DELAYS



Total arrival flow, Q_n = 800 vph

Discharge flow per lane = 1800 vph

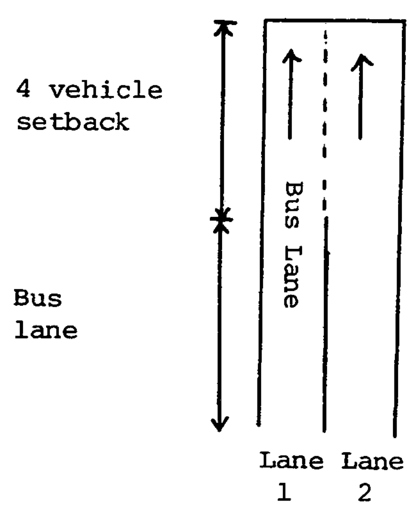
Cycle time, c_1 = 100 secs

Effective green time, g = 50 secs

Effective red time, r = 50 secs

$$\lambda = \frac{g}{c} = 0.5$$

$$x = \frac{q}{\lambda s} = 0.44$$



Entry Layout

APPENDIX D

METHODS OF MODELLING DIFFERENT JUNCTION ENTRY LAYOUTS

APPENDIX D

METHODS OF MODELLING DIFFERENT JUNCTION ENTRY LAYOUTS

A variety of junction layouts were included within the study sites, and these have been grouped within categories, as illustrated in Figure B1, each requiring different methods of approach in the modelling. Some of the study sites contained features from more than one category.

At all sites with lanes containing mixed turning traffic, it was first necessary to determine the proportions of turning traffic in each lane to enable saturation flow to be predicted on a lane-by-lane basis. The formulae used for this prediction are given at the end of this Appendix. The saturation flow prediction formulae are described fully in Reference 17 and are reproduced in summary at the end of this Appendix. These formulae enabled predicted stop-line saturation flows to be calculated for the 'with' and 'without' bus lane situations, as illustrated in Figure 7.3.

Where it was necessary to estimate the maximum queue in a lane (e.g. to model the effective setback for a lane of left turn only traffic) the following equation was used:

$$Q_{max} = q_a t \qquad \text{....... (1)}$$

where Q_{max} = max queue (pcu's)
q_a = arrival flow (pcu's/sec)
t = time from start of red for all vehicles to discharge (secs)

$$t = \frac{rs}{s-qa}$$

where r = red time (secs)
s = saturation flow (pcu's/sec)

These relationships are based on regular arrivals and departures (as shown in Appendix C and assume that all vehicles clear in the green phase.

The basic difference in the modelling of junction entries using CONTRAM and TRAFFICQ was in the treatment of permitted movements. CONTRAM considers each link to be subject to a single queue and a single discharge rate, and lanes with significantly different discharge rates (e.g. opposed right turning lanes) have to be modelled as separate links. TRAFFICQ, on the other hand, allows different lane marking configurations to be represented by appropriate values of link entry saturation flow for each turning movement, as described in Section 7.1.1.

The different categories of entry layout are illustrated in Figure D1 and are described separately below with reference to the modelling methods employed.

Layout 1 was assumed only to cause a reduction in maximum capacity if the setback length was insufficient to hold all vehicles which could discharge during a green phase. Total stop line saturation flow was therefore calculated as described above.

Where saturation flows were markedly different between lanes, as in layout 2 where right turners were subject to opposing flow, the situation was more complex.

Two extreme situations are illustrated in Figures D2A and D2B, the former showing the bus lane having no effect on junction capacity, with the latter showing a dramatic effect. Clearly, the length of queue in the offside lane relative to the setback distance is of key significance. These conditions, which could fluctuate during a peak period, could not be adequately reflected by CONTRAM, unless the two lanes were treated as separate links. This would then introduce short links which are undesirable (see Section 7.2.1). TRAFFICQ should model this situation satisfactorily although queueing assumptions for vehicles undertaking different turning movements may be inappropriate to this situation (e.g. TRAFFICQ assumes that if more than 4 vehicles are queueing to turn right, all following through traffic will use the nearside lane(s)). In practice, only two bus lanes of this type were surveyed: Site 3 operated under the condition in Figure B2B when surveyed, while the right turning flow on Site 8 was too low to cause delay to following through traffic (.e. there was sufficient storage area in the junction to accommodate one or two right turners).

Total stop-line saturation flow for layout 3 in CONTRAM was calculated as shown in Figure 7.3, except that the effective setback length was reduced to the value of Q_{max} (from Equation 1) if necessary. This gave a 'practical' maximum saturation flow for the 'with bus lane' case. The alternative method of modelling would again have been to model the lanes as separate links but, with left turn only lanes usually being very short in these circumstances, this was considered undesirable.

A better way of modelling this situation in TRAFFICQ would appear to be to restrict the left turn and straight-ahead link entry saturation flows to appropriate values for a single lane of traffic.

The situation without the bus lane depended on whether the left turn only lane would have been maintained or whether an ahead/left lane would have been in operation. At sites where a bus lane continued downstream (Sites 1, 12, 13) it was assumed that the left turn only restriction was caused by the bus lane system and would not have occurred without it. This was therefore a disbenefit of the bus lane to non-priority vehicles. At the other site in this category (Site 19) the left turn only lane was assumed to occur with and without the bus lane.

<u>Layout 4</u> depicts a separate right turn only lane, which may also have been subject to different signal timings to through traffic. As queue lengths and delays were different in this lane from other lanes at the stop line, it was necessary to model it as a separate link within CONTRAM, although within TRAFFICQ, separate right turn facilities enabled this movement to be modelled within the same link. Again, appropriate link entry saturation flows were required to reflect the maximum discharge rates for the different turning movements. Right turn only lanes occurred at Sites 6, 10 and 11. While no disadvantage to right turners due to the bus lane was observed at these sites, disbenefits could occur if it caused queues of through traffic to extend upstream of the start of the right turn only lane.

The constricted entry width situation shown in <u>layout 5</u> applied only to Site 7. Junction capacity was unaffected by the bus lane as only a single lane of traffic could pass through it with or without the bus lane. At some sites, constriction occurred on the exit link 'immediately' downstream causing single lane queueing on the bus link. This constriction would have to be represented in the saturtion flow at the upstream stop-line for CONTRAM, but in the link entry saturation flow for TRAFFICQ.

Junctions with no setback, as illustrated in <u>layout 6</u>, as at Sites 10, 11 and 21, allow no interaction between priority and non-priority vehicles and the bus lanes were modelled within both CONTRAM and TRAFFICQ as separate links. This also applied to pelican type pedestrian crossings. One complete queueing lane is lost to non-priority vehicles and saturation flows in the modelling were reduced accordingly for the with bus lane case.

The calculation of the average stop line saturation flow for a flared entry, as shown in layout 7, required the construction of a saturation flow 'profile' for the entry, as shown in the example in Figure 7.3. Two or more steps could be contained in the profile, depending on the extent of the flare, the 'length' of each step being related to the geometric length of that part of the flare. The average stop line saturation flow was then the weighted average of the individual steps (c.f. Equation 1). Again, the bus lane was assumed only to cause a reduction in capacity if the setback length was insufficient to hold all vehicles which could discharge in a green phase.

All calculations above involving a stepped profile were subject to the stop-line saturation flow, so calculated, being higher than that for the lane adjacent to the bus lane. If not, the lower value was adapted.

Entry capacity at roundabouts (layout 8) was calculated using the formulae given in LR942[23]. The effect of a bus lane with a setback at a roundabout entry, as shown in category 8, was taken as that caused by an equivalent flare as predicted by the formulae. In some cases this was superimposed on an already existing 'tighter' flare and capacity could then be theoretically unaffected by the bus lane.

The layouts described above reflect the range of conditions found at the 25 sites surveyed. Other layouts may occur in practice which may required detailed consideration of the probable effects of a bus lane on junction capacity.

Saturation Flow Formulae

1. Lanes not containing opposed right turn movements

The saturation flow is given by:

$$S = \frac{2080 - 140\delta_n - 42\delta_G G + 100(w_1 - \bar{w}_1)}{1 + 1.5f/r}$$

Where: δ_n = 1 for a nearside lane or single lane entry, zero otherwise

δ_G = 1 for an uphill gradient, zero otherwise

G = the gradient in percent

w_1 = lane width in metres

$\bar{w}_1$ = mean lane width recorded in surveys (3.25m)

f = the proportion of turning traffic in the lane
r = the radius of turn for any turning traffic, in metres

2. Lanes containing opposed right turn movements

The saturation flow is given by:

$$S = S_g + S_+$$

Where:

$$S_g = \frac{1850 - 42\delta_G G + 100(w_1 - \bar{w}_1)}{1 + f\left(\dfrac{12\,X_o^2}{[(1 - (fX_o)^2)(1 + 0.6(1-f)N_s)]} + \dfrac{1.5}{r}\right)}$$

and

$$S_+ = (N_s + 1)(fX_o)^{0.2}N_g$$

δ_G, G, W_1 and W_1 are as before

Where f = proportion of right turning vehicles in lane

N_s = number of storage spaces available inside the intersection which right turners can use without blocking following straight ahead vehicles

N_g = number of green phases per hour i.e. $N_g = 3600/\lambda C$ where C is as above and λ is the proportion of the cycle that is effectively green. (In practice where green phases are divided between conflicting movements, the number of occasions in which right turners can clear during the intergreen times would be expressed as N_g = 3600/C.)

X_o = traffic intensity of the opposing stream i.e. $\dfrac{q_o a_c}{s_o g}$

Where: $q_o a$ = opposing arrival flow including left turners but excluding non-hooking right turners (vehs/hr)

s_o = saturation flow for opposing entry, calculated on a lane by lane basis, and summed for multi-lane entries (vehs/hr)

c = cycle time (secs)

g = effective green time (secs)

3. <u>Multi-lane Stop Lines</u>

The saturation flow can be obtained by summing individual lane saturation flows.

The range limits on the above parameters are as follows:

G	:	-7.8 to +8.7 (%)
f	:	0 to 1
r	:	6 to 50 (m)
w_1	:	2.2 to 4.4 (m)
X_0	:	0 to 1
N_g	:	0 to 240
$q_o a$	:	0 to 3000 (vehs/hr)
g	:	15 to 90 (secs)
C	:	40 to 120 (secs)

Mean starting lost time : 1.36 (secs)
mean ending lost time : 0.13 (secs)
PCU factors given in Section 6

FIGURE D1 : JUNCTION LAYOUTS

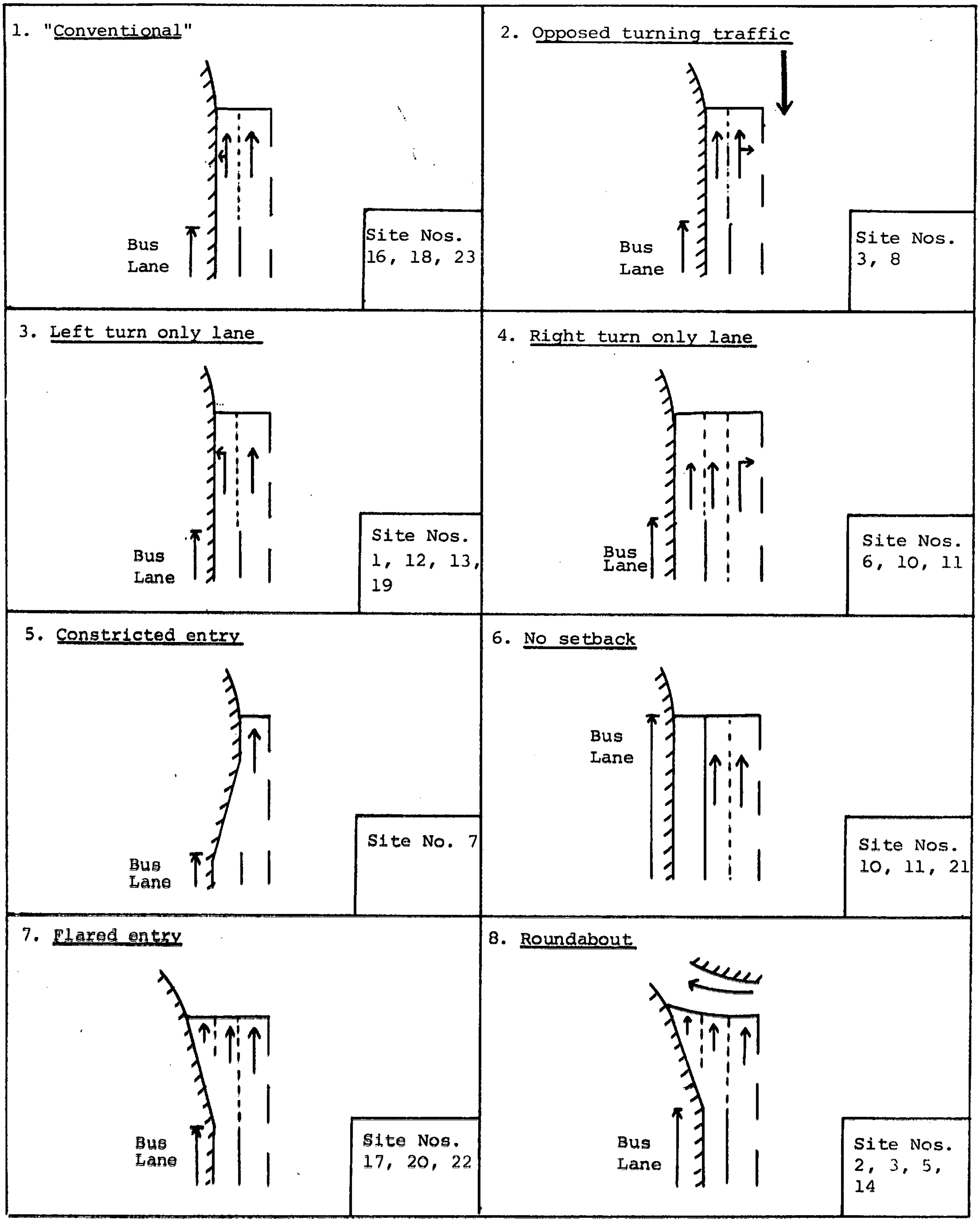
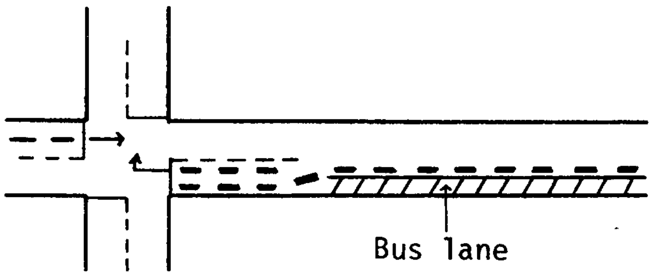


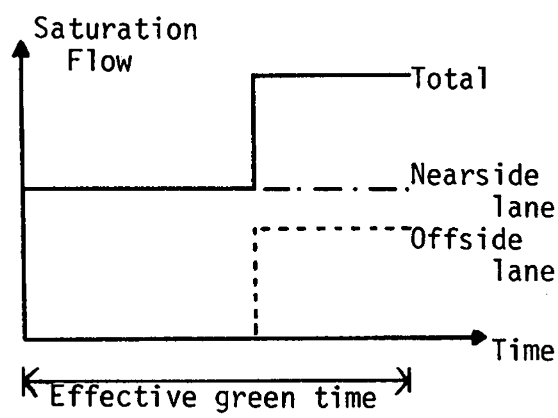
FIGURE D2 : COMBINED EFFECTS OF OPPOSED TURNING TRAFFIC AND BUS LANE ON JUNCTION CAPACITY

EXAMPLE A : NO REDUCTION IN CAPACITY

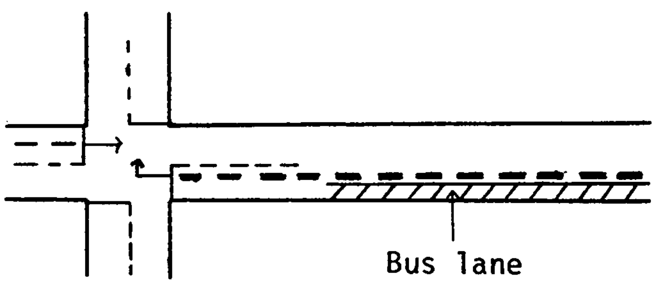


Offside lane queue length never exceeds setback distance

Possible Saturation Flow Profile

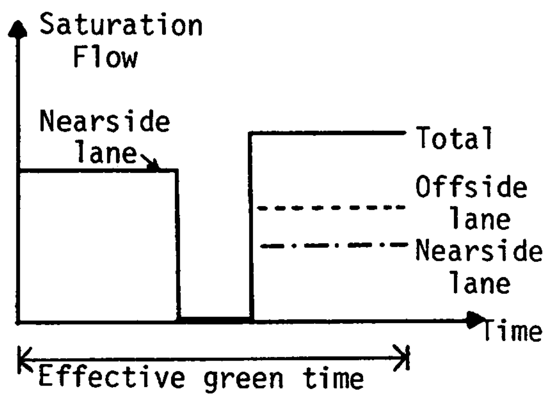


EXAMPLE B : REDUCTION IN CAPACITY



Offside lane queue length of right turners exceeds setback distance and following through traffic blocked. Bus lane violations possible.

Possible Saturation Flow Profile



APPENDIX E

EVALUATION PROCEDURE

APPENDIX E

EVALUATION PROCEDURE

The steps involved in the evaluation procedure described in this Appendix are outlined in the form of a flow chart shown in Figure 1. Descriptions of each step are given in this Appendix, referenced to sections in the main report as necessary. The procedure is intended to include the main elements of evaluation that are likely to be involved at the majority of sites. The relative weighting of the importance of these factors (e.g. economic return against environmental impact) will vary between sites and require judgement, and other factors which have not been identified here may be significant on a site specific basis.

Examples of the application of the evaluation procedure to two bus lanes recently introduced in London are given in Appendix F.

The following notes are related to the flow chart illustrated in Figure 1.

1. IDENTIFY PROBLEM

A Typical problems which may warrant consideration to be given to the introduction of a bus lane include:

(i) With-Flow Bus lane

Traffic congestion causing high and variable delay to buses with associated undesirable effects (e.g. unreliable service, loss of patronage, etc.)

(ii) Contra-Flow Bus Lane

One-way system has increased journey distance/time for buses, separating outward and return routes and causing additional walking time for passengers, loss of patronage, etc.

Other reasons may include the segregation of buses from other traffic where bus flows are high, reducing accident risk (e.g. to pedal cyclists), altering the modal split in favour of public transport, the control of parking/ access,etc.

B Typical problems which may warrant consideration to be given to the removal or modification of an existing bus lane include:

- High delays being suffered by non-priority vehicles possibly exacerbated by the presence of the bus lane.
- Traffic blocking upstream junctions and side roads, causing increased delay to traffic not wishing to use the bus lane link and negating the benefit to priority vehicles.
- Traffic diverting to local environmentally sensitive minor roads or over a wider area.
- Parking and/or moving violations requiring frequent enforcement and reducing effectiveness of bus lane.
- High accident rates on the link after introduction of the bus lane.
- Suspicion of non-optimum design of bus lane (e.g. too short, too narrow, non-optimum setback for the prevailing signal timings, etc.)

2. <u>OTHER SOLUTIONS</u>

Other solutions to the problems(s) identified may include:

- Road construction/widening
- Junction re-design to improve capacity (e.g. conversion to roundabout/signals, flaring, signal staging/timing improvements)
- Introduction of U.T.C. system
- Traffic management measures (e.g. restraint, parking prohibition).
- Re-routing of bus service(s) or other bus priority measures.

If bus lane existing, typical solutions listed above may apply, although others (excluding removal) may include:

- Extension of vehicle classes permitted to use the bus lane.
- Amendment of operational period
- Re-design

3. INITIAL SURVEY OF SYSTEM

No Bus Lane Existing

Geometric details required to ascertain whether there is sufficient existing road space for the bus lane (or whether road could be widened) in accordance with H6/76 and other design guidelines. Relevant measurements include:

- Link length(s)
- Road/carriageway/lane widths
- Number of lanes
- Curvature, gradient, etc. (approximate)
- Junction dimensions (e.g. to check whether modifications that may be required (particularly for a contra-flow lane) could be carried out)
- Layout of surrounding network (to consider diversion possibilities)

Traffic details required to:

(i) Initially consider whether the bus lane might be worthwhile for priority vehicles by measuring bus flows/occupancies and:

a) With-Flow Lanes

The journey time of vehicles from the back of the queue to the proposed end of the bus lane, at regular intervals during the period of interest on one or (preferably) more days. Include possible packing effects (Section 8.3). This gives an estimate of the time able to be saved by priority vehicles.

b) Contra-Flow Lanes

Measurement will depend on system being proposed, but would typically require regular measurement of journey times during period of interest to compare with estimated journey time on new route.

(ii) Initially consider the extent to which the bus lane might disbenefit non-priority vehicles.

a) With-Flow Lanes

If it is known that junction capacity will be reduced (e.g. due to no setback being provided) it may be necessary to model the situation in more detail at this stage. Otherwise:

- Measure maximum queue lengths to estimate new maximum queue lengths with the bus lane, assuming the same number of vehicles queue.
- Consider likely diversions, effects on side road traffic blocking back, etc. from information above.
- Consider effects of/on turning traffic, particularly opposed right turners and vehicles following.

b) Contra-Flow Lanes

Depending on the characteristics of the proposed system, measurements may be required of:

- Non-priority traffic flow in the stream(s) currently including buses (which are to be removed) to estimate, for example, the effect of junction modifications associated with the bus lane.
- Traffic flow in the opposite direction to that of the proposed bus lane, to assess the effects of the loss of a lane and (perhaps) of junction modifications.

(iii) Other items which may be affected by the bus lane and require measurement/assessment include:

- Parking provision/activity
- Loading/unloading provision, loss of access, etc.
- Bus passenger walking times (e.g. due to relocation of bus stop in contra-flow system)
- Pedestrian activity (e.g. volume and location)

Bus Lane Existing

The feasibility of bus lane removal/modification will not normally be in doubt, and, at this stage, an indication of the disbenefit to those vehicles concerned may suffice through its removal/modification. (Removal will normally only disbenefit priority vehicles whereas modification could affect priority and/or non-priority traffic.) This may be obtained from relevant measurements as described above. Measurements associated with a more detailed evaluation and/or a 'before' and 'after' study are discussed in Item 6 below.

4. SELECT EVALUATION PROCEDURE

a) Computer modelling is recommended for the evaluation of with-flow bus lanes if:

(i) The proposed system is complex (e.g. more than one link affected)
(ii) Numerous alternative options are to be assessed (e.g. variations in layout, signal timings, etc.)
(iii) The bus lane will restrict junction capacity.
(iv) Traffic diversions and/or blocking back across significant side roads and/or through upstream junctions is likely to be significant (as determined from measurements described in 3 above).

Modelling is also recommended when it is proposed to remove or modify the bus lane and any of these circumstances exist.

b) For with-flow bus lanes on single links where none of the above conditions apply, simpler non-modelling techniques may be applied (see Section 7.5).

c) An adequate evaluation of a contra-flow bus lane will normally involve computer modelling, unless journey time considerations are not significant or can be easily estimated. Modelling allows an evaluation to be made of:

- The effects of the change in traffic assignment and consequent delay
- The effects of modifications in junction control characteristics.

5. MODELLING

With-Flow Bus Lanes

Subject to the comments in Sections 7.3 and 8.3, BLAMP is considered to be the most suitable model for the evaluation of the effects on journey time/delay of a with-flow bus lane on a single link provided the following effects are insignificant:

- Movements to or from side roads
- The blocking of other traffic not wishing to use the bus lane link
- Traffic diversions

Other models which can also be used in these circumstances include ARCADY, PICADY or OSCADY, although these have not been evaluated in this study.

TRAFFICQ or CONTRAM can also be used under these circumstances although where a setback exists or is proposed which restricts junction capacity, modelling accuracy is diminished (see Section 7.1.1, 7.2.1 and 8.4.1.2). Subject to this constraint, either of these models can be used for evaluating larger networks containing with-flow bus lanes.

The characteristics of these models are described in Section 7.

Contra-Flow Bus Lanes

Either TRAFFICQ or CONTRAM are suitable for the evaluation of the effects on journey time/delay (and fuel consumption) of a contra-flow bus lane. CONTRAM is preferred where vehicle routes are uncertain or complex and/or where traffic signal optimisation is required (see Sections 7.1.2 and 7.2.2).

6. DATA REQUIREMENTS

a) Modelling

The main data requirements for each model are listed in Table 7.2, further details being given in the individual program User Guides. The models are particularly sensitive to the following parameters which should be carefully measured:

(i) origin-destination traffic flows (in, say, 15 or 30 minute intervals over the modelled period depending on the variation in traffic flows related to the model capabilities). These will typically take the form of classified turning counts of each relevant junction. A count upstream of any queues likely on the bus lane link is also required to give a measure of traffic demand. (A count at the junction immediately downstream of the bus lane will only reflect junction capacity and should not be used as the demand flow.) Circulating flows on roundabouts (where present) are also required.

(ii) stop line saturation flows at traffic signals, which should preferably be measured (rather than predicted) for each relevant link on a lane-by-lane basis if TRAFFICQ or BLAMP are being used. The saturation flow for the lane(s) adjacent to the bus lane is also important in BLAMP. Total stop line saturation flows for each link are required by CONTRAM. The saturation flow measurements should also allow estimates to be made of starting and ending lost times. A key element in the evaluation will be the assumption(s) made about the effect of the bus lane on saturation flow/capacity, i.e. will/has the bus lane reduced the capacity or are other factors overriding? (e.g. exit blocking, presence of bus stops, etc.). This may not be clear from these measurements and careful site observation/judgement will be required.

(iii) traffic signal timings

(iv) roundabout entry capacity (if applicable)

(v) cruise speeds (less important where 'continuous' queueing occurs).

(vi) vehicle journey times for priority and non-priority vehicles. These are required for calibrating the model. Measurements are required on the bus lane link itself, between a point upstream of any likely/existing queue on the link and either the end of the bus lane or the stopline of the downstream junction. (The latter location is preferred where the setback is not fully used.) Journey times may also need to be measured on diversion routes and on significant side roads which may be/are affected by the bus lane. (Simpler queue length measurements are likely to be sufficient for the side roads.) It is recommended that journey time measurements be obtained through registration number matching (see

Section 6) on 2 or more days depending on the variability, although the floating car technique (see Reference 18) could be used on a greater number of days particularly for larger networks.

(vii) queue length on the bus lane link at regular intervals. These measurements may be necessary to:

- determine the optimum length of the bus lane
- assess the modelling accuracy
- assess the occurrence of existing/likely blocking back or traffic diversion conditions, which may indicate whether modelling is worthwhile.

(viii) other data which may need to be collected include:

- parking characteristics where these effects can be modelled (e.g. in terms of available link width, saturation flow, effect on bus speeds, etc.)
- the stopping time and associated acceleration/deceleration effects for buses at bus stops, as this effect is not accounted for in the modelling
- walking time for bus passengers, if bus stop location(s) to be significantly altered and waiting time (likely to be insignificant change)
- bus arrival reliability (e.g. arrival headways)

b) Non-Modelling

The main data requirements for non-modelling techniques are those described in items (i), (vi), (vii) and elements of item (viii) as necessary. Additional data may be required according to the method of analysis (see Section 7.5).

c) Before and After Data

The usual requirements are as described in items (i), (vi), (vii) and elements of (viii) as necessary.

7. The modelling methods and procedures adopted in this study are fully described in Sections 7 and 8. The main recommendations applying to TRAFFICQ and CONTRAM are listed below.

With-Flow Bus Lanes

a) No setback at junction

Model the lanes containing priority and non-priority traffic as separate links and assign flows accordingly. (This is also applicable to bus lanes approaching pedestrian crossings).

b) Setback at junction

- Model the bus lane link as a single link (e.g. as in Figure 7.2 rather than 7.1) to which all traffic is assigned. Model the effect of the bus lane on non-priority traffic by reducing the number of lanes over the bus lane length (TRAFFICQ) or reducing the storage capacity (CONTRAM). Only change vehicle cruise speeds if the effect of the bus lane is known (unlikely). From measurements of saturation flow construct a saturation flow profile as described in Section 7 and illustrated in Figure 7.3. Assess whether the bus lane is reducing/will reduce capacity, taking into account existing/likely packing factors (Section 6.4). Consider the importance of the simplifications in this approach and the prediction of the time 't' (Figure 7.3) as described in Section 7.1.1 under "SATURATION FLOWS". If reduction in capacity is predicted, this is reflected by reducing the stop line saturation flow or, for TRAFFICQ, the link entry saturation flows depending on the circumstances (see Section 7.1.1). Under these conditions, modelling with TRAFFICQ or CONTRAM may produce significantly biased results when the maximum queue is less than could fit into the setback area (see Section 7.1.1), and modelling with BLAMP may be preferred.
- Different junction layouts are likely to require different methods of approach in the modelling - examples of the methods used at the study sites are described in Appendix D.
- Where the introduction of a bus lane is being evaluated, calculate the predicted journey time for priority vehicles from the results of the modelling for all traffic, as

described in Section 7.1.1. These predictions have a degree of uncertainty to be considered (see Sections 7.1.1 ("BUS JOURNEY TIMES") and 8.4.4), and alternative calculations, or the use of BLAMP may be preferred. (The time associated with bus stops is not considered in the modelling of either the 'with' or 'without' bus lane situation and has to be included externally as necessary.) Consideration should be given to factors which may reduce/be reducing bus journey time savings from those predicted (e.g. parking violations, high pedal cycle flows, etc. - see, for example, Sections 6.5.1.4 and 6.5.1.5).

- For roundabouts, the effect of a setback on entry capacity can be estimated by equating the setback to a flare, although there is evidence that this may overestimate the effect of the flare under some circumstances. A better assessment is likely to be obtained by a consideration of the gap acceptance characteristics. This involves the measurement/assessment of the maximum number of vehicles accepting gaps in the circulating traffic under saturated entry conditions to determine whether (and by how much) the bus lane is restricting/will restrict this entry capacity. Any capacity restrictions can be reflected in the models by appropriate specification of the input parameters (see Sections 7.1.1 and 7.2.1).

Contra-Flow Bus Lanes

These lanes should be modelled as separate links to those carrying non-priority traffic, traffic flows being assigned accordingly. Journey time predictions for priority vehicles are therefore obtained directly from the model output. Junction setbacks do not occur with contra-flow lanes and the problems outlined in Section b) above do not therefore apply.

General

It is likely that the model will have to be calibrated to some extent to accurately reflect existing conditions. This may be achieved by adjusting the relevant saturation flow(s) within reasonable limits until observed and predicted journey times are not significantly different.

Both TRAFFICQ and CONTRAM give details of aggregated vehicle mileage and flow weighted journey times for the network, and these should be used where more than just the effects on vehicles on the bus lane link are being considered.

8. ECONOMIC EVALUATION

This typically involves a comparison of implementation/removal/ modification costs with first year economic benefits to give a first year rate of return. Longer term evaluation (e.g. as in COBA) is likely to be too uncertain.

The main costs are usually associated with road markings and signs, although others may include surface dressing, junction modifications, kerb re-alignment, etc. Other costs to be considered include maintenance, enforcement and design/ evaluation.

The main benefits/disbenefits usually accrue from journey time changes for priority/non-priority traffic and (to a lesser extent) changes in vehicle operating costs. Other quantifiable benefits to be considered (as described in Section 9) may include:

- Bus passenger walking and/or waiting time reductions
- Improvements in bus service reliability
- Increased numbers of bus passengers.

The calculation of economic benefits is described in Section 9.

9. OTHER EVALUATION CRITERIA

These may include:

- Environmental effects particularly with respect to traffic diversions through environmentally sensitive areas.
- Effects on pedestrians.
- Effects on parking/loading characteristics, loss of access/trade, etc. which cannot be quantified.

A framework of likely benefits/disbenefits may need to be set up and each item subjectively ranked to give an overall appraisal.

10. ACCEPTANCE OF SCHEME

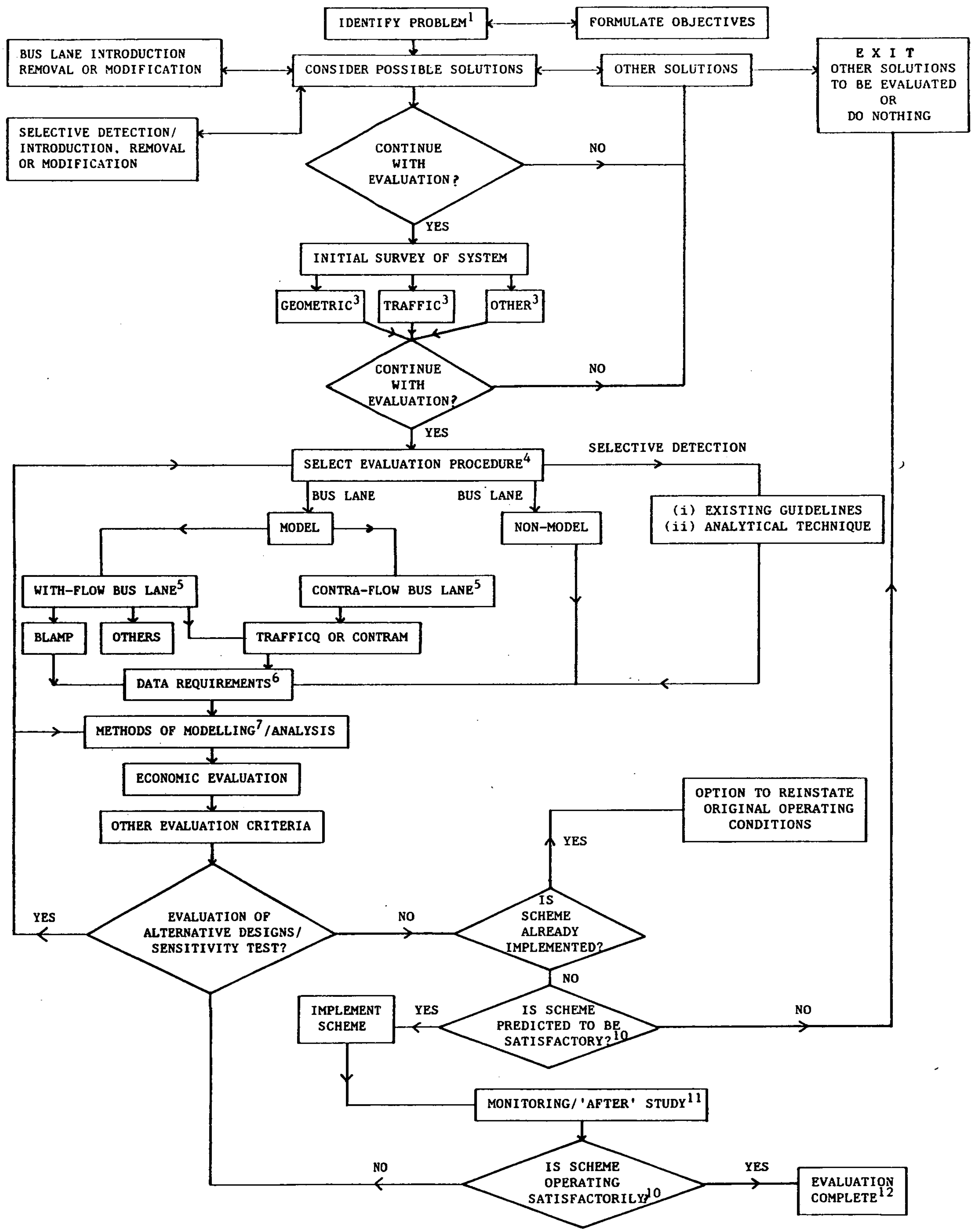
This may be based on an acceptable predicted/measured first year rate of return coupled with a consideration of the other evaluation criteria as described above.

11. The comparison of vehicle travel times before and after implementation of a scheme requires consideration to be taken of the effects of variations in other conditions which may have occurred, particularly in traffic flows. An analysis of variance, as described in Reference 18 is appropriate.

12. FUTURE MONITORING

With bus lanes usually operating at around capacity for significant periods, operational performance is sensitive to variations in network/traffic conditions. Further monitoring/evaluation may therefore be required if such changes occur (e.g. in traffic growth, modal split, traffic signal staging, junction control, etc.).

FIGURE E1 : FLOW CHART OF BUS LANE EVALUATION PROCEDURE



APPENDIX F

EXAMPLES OF APPLICATION OF EVALUATION PROCEDURE

APPENDIX F

EXAMPLES OF APPLICATION OF EVALUATION PROCEDURE

1. INTRODUCTION

Two with-flow bus lanes implemented in London were selected to independently assess the evaluation procedure described in Appendix E. The assessment included 'before and after' surveys to illustrate the evaluation procedure, test the accuracy of the predictions of the 'after' situation and to amend the evaluation procedure in the light of the results from the 'after' surveys. While a full assessment was undertaken, delays in implementing the bus lanes and changes in control strategies at the junction led to some difficulties and uncertainties in interpreting the results, as described in Section 11.

The examples described here are limited to illustrations of the evaluation procedure and do not include a detailed economic analysis of the likely benefits of the bus lanes. The evaluations differ from those carried out at the other sites described in the main report in that those bus lanes were already operational and the alternative being evaluated was their removal - nevertheless the two procedures are compatible, as described in Appendix E and Figure E1.

The following sections describe the evaluation in the order set out in Appendix E, with section numbers being compatible. The 'before' surveys are therefore described in Sections 5 to 7, while the 'after' surveys and their results are described in Section 11.

1.1 The Sites

The bus lanes under evaluation are located within the London Boroughs of Lambeth and Southwark (as shown in Figure F.1). They are situated on Denmark Hill (northbound) and Champion Park (westbound) respectively, forming approaches to the same signal controlled junction. Detailed drawings of the sites are given in Figure F.2. Denmark Hill is situated on the A215 and, over the proposed bus lane section, is a single carriageway road fronted mainly by residential properties. It has sufficient width for two lanes of traffic in each direction although only the centre line is marked. Champion Park, situated on the A2216, is also a main single carriageway ex-metropolitan road, fronted by residential properties, a main line

British Railway station (Denmark Hill) and institutional buildings. Over the proposed bus lane section the road is wide enough for 3 lanes. Both roads are subject to a 30mph speed restriction.

2. THE PROBLEM

The problem at Denmark Hill is stated in the Transport Committee report by the Controller of Transportation and Development of the Greater London Council (GLC) under the "Statement of Reasons".

"Traffic queues frequently develop in Denmark Hill during the morning peak approaching the Camberwell New Road/Denmark Hill junction. These queues often extend across the junction with Champion Park and beyond. The bus lane has been designed to protect buses from this congestion and thereby reduce delays".

The problem is similar at Champion Park as stated in the Statement of Reasons in the Transport Committee report for this bus lane:

"Champion Park suffers from traffic congestion during the morning peak. The westbound with-flow bus lane will protect westbound buses on Champion Park and improve bus journey times."

On-site observations have shown that the sites have a common main downstream link, Denmark Hill north, which becomes congested as northbound traffic saturates the main route through Camberwell, this congestion spreading upstream to the proposed bus lane links. With-flow bus lanes are already in operation through Camberwell. While it is possible that these bus lanes are causing additional delay to northbound traffic their efficiency of operation is not considered here.

2.1 Other Possible Solutions

Other possible solutions to this problem of congestion which could be evaluated include:

(i) Removal/redesign of the bus lanes further downstream, if an evaluation of these lanes indicated that they are causing unnecessary additional delay to non-priority traffic. If not, their removal, while considerably reducing queues and delays on the bus lane links under evaluation here (due to the increase in queueing capacity downstream) would be unlikely to provide an overall benefit.

(ii) New road construction/junction widening etc. This may not be possible within the built up area of Camberwell.

(iii) Re-timing/staging of critical traffic signals.

(iv) Other traffic management options (e.g. traffic restraint, re-routeing).

3. INITIAL SURVEY OF SYSTEM

Denmark Hill

(i) Geometric :
- Link length ≃ 800m
- Road width ≃ 14m
- Curvature : Only significant at junction with Champion Hill
- Gradient : Slightly downhill towards junction with Champion Park
- Junction modifications required : none
- Alternative routes : Possible 'rat run' via Ferndene Road

Conclusion : Bus lane possible

(ii) Traffic :
- Approximate flow of scheduled buses in morning peak = 21/hr
- Current 'unnecessary' maximum delays to buses ≃ 3.5mins/bus (as stated in Committee report)
- Current maximum queue lengths ~ 300m ≃ 500m with bus lane, which is less than link length ∴ blocking back unlikely, bus diversions via Ferndene Road possible
- Non-priority traffic unlikely to suffer significant disbenefit as congestion caused by exit blocking
- Opposed right turning traffic ≃ 2 vehs per cycle ∴ following through traffic not blocked provided setback adequate

Conclusion : Bus lane likely to be beneficial

(iii) Junction Control : Fixed time signals (non UTC)

Conclusion : Suitable for bus lane

(iv) Other :
- Waiting/loading restrictions currently in force. Ammendments required should cause minimal disbenefit
- Access to residential properties not affected

- Pedestrian crossing to be retained
- Bus stop sitings to be retained

Conclusion : No significant disbenefits from bus lane

Champion Park

(i) Geometric :
- Link length ≃ 800m
- Road width ≃ 10.6m
- Curvature : Significant bend (radius = 15m) 300m from end of link
- Gradient : Insignificant
- Junction modifications required : none
- Alternative routes : None in immediate vicinity (Grove Lane to remain inaccessible)

Conclusion : Bus lane requires small offsetting of centre line, which should not cause significant disbenefit to traffic in opposite direction which will have 4.6m carriageway width. Curvature prevents bus lane from starting until after junction with Grove Lane. (Queues rarely extend upstream of this point so local road widening unlikely to be worthwhile.)

(ii) Traffic :
- Approximate flow of scheduled buses in morning peak = 19/hr
- Current 'unnecessary'maximum delays to buses ≃ 1.5mins/bus (as stated in Committee report)
- Current maximum queue lengths ~ 200m
  Maximum bus lane length ≃ 250m
  Queue lengths should not be affected by bus lane, as bus lane replacing existing parking
- Non-priority traffic unlikely to suffer significant disbenefit as congestion caused by exit blocking
- No opposed right turning traffic

Conclusion : Bus lane likely to be beneficial

(iii) Junction control : Fixed time signals (non UTC)

Conclusion : Suitable for bus lane

(iv) Other :
- Parking currently widespread in proposed bus lane area which will be restricted. Most parking is long stay (e.g. during working day). Alternative

parking for ~ 40 cars on neighbouring streets will increase occupants' walking time. This should be evaluated.

- Ammendments to and impositions of waiting/loading restrictions required on both sides of road. Effect significant only on shops fronting Grove Lane. These have no rear access and deliveries will therefore have to be trolleyed for 25m.
- No disbenefit to pedestrians foreseen
- Bus stop sitings to be retained

Conclusion : Effect of bus lane on parking/loading activities should be evaluated. Effectiveness of waiting/loading restrictions should be monitored if implemented.

4. SELECT EVALUATION PROCEDURE

The criteria for the selection of the evaluation procedure are described in Appendix E, Section 4. Although congestion on Denmark Hill is controlled mainly by exit blocking, computer modelling may be usefully employed to assess the effects of:

(i) Reduced capacity (caused by the proposed 47m setback which is less than theoretically optimum) which may occur when the exit is clear.

(ii) Traffic diversions which may accompany the bus lane (e.g. via Ferndene Road).

(iii) Increased queue lengths and delays for side road traffic (e.g. to vehicle emerging from Champion Hill).

(iv) Increased delays to right turning vehicles (due to their increased interaction with through traffic).

The Champion Park bus lane, on the other hand, simply involves replacing an existing line of parked vehicles with a bus lane and a small offsetting of the centre-line. The bus lane wwould terminate very close to the point that permitted parking terminates (within 1 vehicle's length) and junction capacity should therefore not be significantly affected by the bus lane provided the parking provision currently allowed is fully used. Queue lengths should also not be affected by the bus lane. Under these circumstances, computer modelling of the bus lane would not be worthwhile.

For the purposes of these illustrations however, both bus lanes have been modelled within a single network, and non-modelling techniques have also been applied to each.

5. NON-MODELLING TECHNIQUE

5.1 Data Requirements

These are described in Appendix E, Section 6 and include:

(i) Classified traffic counts
(ii) Journey times for priority and non-priority traffic
(iii) Measurements of queue length

Data covering items (i) and (ii) were collected during the course of 'before' surveys carried out over the morning peaks of the 4^{th}, 5^{th} and 6^{th} of February 1986. (Additional data for computer modelling was also collected as described in the following Section). 'Before' surveys conducted by the GLC in June 1985, included measurements of queue lengths on Denmark Hill, and a good journey time/queue length relationship was developed. It was therefore decided not to measure queue lengths in the February surveys, but to infer them from this relationship. Similar data was collected for the 'after' surveys in June 1987 as described in Section 11.

Environmental conditions were favourable for the surveys of the 4^{th} and 5^{th} of February, but snow on February 6^{th} resulted in the unusual traffic characteristics of reductions in demand and saturation flow combining to produce increased delay as illustrated in Figures F3, F4 and F5. These results have therefore been excluded in this illustration of the evaluation procedure as being untypical, but would normally be included if the extent of such occasions could reasonably be predicted on an annual basis.

The classified traffic counts at the stop lines at Denmark Hill and Champion Park are summarised in Table F1, these figures being averages of data collected on the 4^{th} and 5^{th} of February. Counts are given for the different vehicle types over 15 minute periods and also as 15 minute and hourly values both in terms of vehicles and pcu's. (Taxis would normally have been measured as a separate category as they are permitted to use the bus lanes, but were omitted on this occasion due to their very low numbers (less than 0.5% of total traffic)).

The average journey times for buses and non-priority vehicles in 15 minute periods throughout each survey are given in Table F2, together with their associated sample sizes and standard deviation. The journey times for buses include the time spent at bus stops. The variation in journey time both within and between survey days is illustrated in Figure F4. This figure also gives equivalent journey time profiles recorded by the GLC in their surveys in June 1985 for comparison. Considerable variation is evident, typical of sites where capacity is controlled by exit blocking to various degrees. Journey times on both Denmark Hill and Champion Park were measured over distances chosen to be both in excess of queue lengths and to be compatible with previous GLC surveys. The distances were 730 metres and 814 metres respectively. Table F2 also contains average journey times for the surveys of the 4th and 5th of February combined, which are used in the following analyses.

Queue lengths recorded by the GLC on Denmark Hill on three separate days in June 1985 are illustrated in Figure F6 in relation to corresponding journey time measurements. This graph illustrates both the variation in queue lengths and corresponding journey times between days, and the good linear relationship between the two parameters. The maximum journey time recorded in our 'before' surveys, which are being evaluated here, was around 300 seconds which corresponds to a queue length of some 250 metres. In the 'with' bus lane situation the equivalent number of vehicles would extend the queue length to around 450m. The bus lane length of 506m (including the setback) should therefore be adequate on most occasions, although if the conditions of June were repeated the queue in the 'with' bus lane case would exceed 700 metres (i.e. nearly to the upstream junction). Modelling may well be preferred to assess the likely effects of these variations on factors such as blocking back, side road delays and re-assignment, which are ignored in the simple technique described in the following Section.

5.2 Evaluation

In this example, average journey times and flows from surveys conducted on 4th and 5th of February 1986 are used. The method of estimating journey times for the 'with' bus lane situation, which is described in Section 6.4, is based on the expression:

$$T_a q_a = T_p q_p + T_{np} q_{np} \qquad \ldots\ldots \quad (1)$$

Where q_a = total flow (pcu's)
q_p = flow of priority vehicles (pcu's)
q_{np} = flow of non-priority vehicles (pcu's)
T_a = average journey time for all vehicles without the bus lane
T_p = average journey time for priority vehicles with the bus lane
T_{np} = average journey time for non-priority vehicles with the bus lane

For brevity, this evaluation has been restricted to Denmark Hill

q_a = 2214 pcu's (Table F1A for 2 hour survey period)
q_p = 72 pcu's (Table F1A for 2 hour survey period)
q_{np} = 2142 pcu's (Table F1A for 2 hour survey period)

T_a = 174 secs (Table F2A for non-priority vehicles: Bus journey times excluded as they include effects of bus stops)

Measurements of the without bus lane situation do not yield values of T_p and T_{np} in equation (1) and it is therefore necessary to estimate one of these parameters. One method of readily estimating T_p is from measurements of journey time and queue length (see Figure F6) as follows :

The average journey time corresponding to a queue of 47m (which corresponds to a full setback unavoidable to buses) = 110 secs. This can be assumed to be the maximum journey time for buses in the with bus lane situation, from the start of the bus lane to the stop line assuming no violations. In the without bus lane situation this journey time is exceeded in all time intervals except interval 1 (Table F2A).

The maximum journey time for buses for the 'with' bus lane situation is thus 110 seconds unless the queue length exceeds the bus lane length. For the 'with' bus lane case, this would occur when the number of pcu queueing is:

$$[(2 \times 47) + (458)]/5.5 = 100 \text{ pcu's}$$

The equivalent length of this queue for the without bus lane situation

$$= \frac{100 \times 5.5}{2} = 275\text{m}$$

This is equivalent to an average journey time of around 320 secs, which was not exceeded in the surveys of the 4th and 5th of February (Table F2A) and queues can therefore be assumed not to exceed the bus lane length. (If this had occurred, the maximum journey time saving for buses would be 320-110 secs = 210 seconds.)

In time interval 1, the journey time for buses with the bus lane (excluding stops) would be 73 secs (see Table F2A). This is because the queue length would be less than the setback distance and average journey times for all traffic would be the same with or without the bus lane. However, the journey time for buses with the bus lane for time intervals 2 to 8 would be 110 seconds (see above). Therefore the average journey time for buses with the bus lane is given by :

$$T_p = (73 \times \frac{1}{8}) + (110 \times \frac{7}{8}) = 105 \text{ secs}$$

i.e. the bus lane saves buses (174 - 105) secs = <u>69 secs on average.</u>

Where a relationship of the form in Figure F6 is not known, T_p could alternatively be estimated as described in Section 6.4, the two methods being expected to give comparable results.

∴ From equation (1) above,

$$\begin{aligned} T_{np} &= (T_a q_a - T_p q_p)/q_{np} \\ &= [(174 \times 2214) - (105 \times 72)]/2142 \\ &= 176 \text{ secs} \end{aligned}$$

∴ non-priority vehicles suffer an increased journey time due to the bus lane of (176 - 174) = <u>2 secs/veh</u>

For simplicity this example has been based on average values over a whole peak period. However, where bus flows/occupancies vary significantly during a peak period in line with variations in journey times, calculations as above may be biased to some extent and similar calculations may then be required over smaller time periods and subsequently aggregated.

6. MODELLING

The two bus lanes have been modelled within a single overall network using CONTRAM and TRAFFICQ but as individual links using BLAMP.

6.1 CONTRAM and TRAFFICQ

6.1.1 Data Requirements

The data requirements for modelling the bus lanes are described in Appendix E, Section 6. The data collected *in addition to that described in item 5 above* covered:

(i) *Origin-destination traffic flows.* These were collected in the form of upstream main road traffic counts or junction turning counts. Traffic counts were taken at:

a) Denmark Hill, immediately north of its junction with Sunray Avenue, to obtain the demand profile for the Denmark Hill bus lane.
b) Grove Lane, immediately north of its junction with Grove Hill, to obtain the demand profile for the Champion Park bus lane.
c) Ferndene Road, as it joins Denmark Hill, as it may be used as a 'rat run' subsequent to bus lane implementation.

Turning counts recorded by the GLC in their June 1985 surveys were also available and used in the modelling. These covered:

d) Movements into and out of Champion Hill.
e) Movements out of Sunray Avenue into Denmark Hill.
f) The U-turn movement from Champion Hill into Grove Lane north, which avoids congestion through Camberwell. (This movement has been discouraged by the construction of a solid central reservation.)
g) The right turning movement from Champion Park into Windsor Walk, which is also used by some traffic to avoid congestion through Camberwell.

(ii) *Stop line saturation flows.* With congestion on both bus lane links being caused mainly by exit blocking, it was essential either to model the downstream links causing this congestion or to accurately reflect actual discharge rates from the links. The former option was rejected due to the complex nature of the downstream network and traffic conditions, the uncertainty of the location(s) of the cause of the congestion and the low likelihood of being able to reflect current queueing characteristics on the bus lane links under these circumstances. Saturation flows were therefore measured on each survey day at the stop lines of both bus lane links: The resulting saturation flow profiles are illustrated in Figure F5. These show the variation in saturation flows in 15 minute periods and the trend of decreasing saturation flow with time at Champion Park, neither condition being able to be reflected in these models (c.f. BLAMP, Section 6.2). The average saturation flows on Denmark Hill and Champion Park for the surveys of 4th and 5th February were 2249 and 2241 pcu/hr respectively, compared to theoretical[17] values for these stop lines of around 3500 pcu/hr. This clearly demonstrates the effect of the exit blocking.

The standard method of measuring saturation flows which was adopted allowed starting and ending lost times to be calculated. These lost times (together with the saturation flows) are summarised in Table F3. The negative lost times reflect some violations of the signals under exit blocking conditions while the higher end lost times for Champion Park reflect the exit being frequently blocked at the end of a green phase while the approach was still saturated. These values may be compared with the typical values of total lost time of 1 to 2 seconds recorded elsewhere[16,17].

(iii) *Traffic signal timings.* The signals were operating to a fixed 60 second cycle throughout all surveys. The combined green and amber periods allocated to the Denmark Hill and Champion Park approaches were also fixed at 29 seconds and 23 seconds respectively.

(iv) *Cruise speeds.* These were measured for each link being modelled

(v) *Other information.* This included:

- Details of levels and location of parking on Denmark Hill and Champion Park. It was observed that parking space on Champion Park was sufficiently utilised throughout the survey periods to prevent traffic from using the nearside lanes over the equivalent length of the proposed bus lane. Parking on Denmark Hill was noted but was generally insignificant.

- Queue lengths on Ferndene Road where it joins Denmark Hill which, with corresponding flow records, allowed delays to be calculated for comparison both with model predictions and with equivalent data after introduction of the bus lane.
- The time spent by buses at bus stops was not recorded: Measured bus journey times with and without the bus lane include bus stopped time but predicted values (as modelled) do not. However, the journey time difference should be equivalent in each case provided there is no change in bus stopped time between the 'with' and 'without' situations (a reasonable assumption). If the evaluation is based on modelling, bus stopped time should be added to the predicted journey time if the appropriate average speed is to be used for vehicle operating cost calculations. This could be estimated in this example as the difference in average journey time between buses and non-priority vehicles from the 'without' bus lane measurements.

Passenger walking times to bus stops were not affected by the bus lane and were not therefore measured. Effects on bus arrival headways (and associated passenger waiting times) were considered best assessed from modelling predictions rather than measurements on a limited number of days on which unknown factors external to the bus lane could have been significant.

6.2 BLAMP

The data requirements for BLAMP are described in Appendix B. This data was incorporated within measurements described in Sections 5 and 6.1 above.

7. METHODS OF MODELLING/ANALYSIS

The methods involved are summarised in Appendix E, Section 7, which refers to further explanation in the main text.

7.1 CONTRAM and TRAFFICQ

The network layouts for modelling with CONTRAM and TRAFFICQ are illustrated in Figures F7A and F7B respectively. The following points should be noted.

(i) Only traffic in the direction of interest has been modelled.
(ii) The networks cover links likely to be affected by the bus lane under current traffic conditions - modelling future performance after increased traffic growth would require a larger network to be modelled (e.g. at least incorporating the Herne Hill Road/Denmark Hill junction in detail).

An example of the 'without' bus lane input data for CONTRAM for the surveys of 4th and 5th February combined is given at the end of this Appendix. The data items changed when modelling the 'with' bus lane situation are 'boxed' in this output, the corresponding values being given beneath. With reference to Appendix E, Section 7 and by way of further explanation:

(i) *Saturation Flows*

'Standard' saturation flow values (e.g. 1800 pcu/hr/lane) were used at stop lines except for the two critical stop lines at the ends of the two bus lanes, where measured values were used for the 'without' bus lane situation. Saturation flows for the 'with' bus lane situation were calculated as illustrated in Figure 7.3, Layout A.

The simplification inherent in this approach, as described in Section 7.1.1 ("SATURATION FLOWS") were considered to be reasonable in this example.

For example, for Denmark Hill, for the survey of 4th February.

S_w = 2195 pcu/hr
g = 30 secs
Setback = 47m, ∴ number of pcus which can fit in setback (both lanes) = (47x2)/5.5 = 17

Assuming that the setback will be fully used (reasonable under conditions of exit blocking with a 2 lane exit)

t = (17 x 3600)/2195 = 27.9 secs

Assuming the saturation flow for the lane adjacent to the bus lane will be 1800 pcu/hr.

Then S = [(2195 x 27.9) + 1800 (30 - 27.9)]/30

= 2167 pcu/hr

The reduction in predicted saturation flow due to the bus lane is only therefore 1.3% which could probably be ignored in practice bearing in mind the other uncertainties in evaluation. Clearly the setback provision is well matched to actual discharge rates under these conditions. Similar calculations for each survey at each site gave the following results, which may be related to the without bus lane saturation flows given in Table F3.

Survey Date	Predicted Reduction in Saturation Flow Due to Bus Lane (%)	
	Denmark Hill	Champion Park
4th Feb, 1986	1.3	0.6
5th Feb, 1986	2.5	2.1
6th Feb, 1986	0	0

(ii) *Origin-Destination Movements*

Demand flows estimated from link and junction counts taken upstream of the bus lanes (see Section 6.1.1) did not exactly match the stop line counts due to the low flow origin/destination movements not measured (e.g. residential properties, minor side roads). Origin-destination flows were therefore factored by a common ratio such that the (key) total stop line flows were maintained along with the appropriate demand profiles.

(iii) *Loss of Queueing Space due to Bus Lane*

This was reflected in CONTRAM by reducing the link storage capacity (as shown in the data base example at the end of the Appendix) for links 401, 501, 601. No queueing space was lost on Champion Park as the bus lane was replacing parked vehicles. The bus lane was reflected in TRAFFICQ by reducing the link width by 1 lane over the sections of each link containing the bus lane.

The data base for TRAFFICQ was similar to that for CONTRAM illustrated at the end of the Appendix and has not therefore been included.

7.1.1 Results

CONTRAM

The results of the CONTRAM modelling are given in Table F4. The following explanations/comments are relevant:

(i) The first run of CONTRAM for the 'without' bus lane situation gave predicted journey times statistically similar to those observed, except for the survey of 6^{th} February when traffic performance was affected by adverse weather conditions. Measured versus predicted journey time profiles are illustrated in Figure F8. This result was encouraging in view of the high levels of traffic intensity being modelled (up to 1.2) and meant that 'calibration' was unnecessary.

(ii) Journey times were calculated by adding the cruise time to the predicted delay for each relevant section and within each time period and averaging over all time periods. Considering the example in Table F5, the overall journey time (T) for the Denmark Hill bus lane links (Nos. 401, 501 and 601), which have cruise times of 28, 10 and 10 seconds respectively, is given by:

$$T = 28 + [10+10+10+10+10+38+69+87]/8$$

$$+ [39+40+39+52+120+193+193+193]/8 = 168 \text{ secs/pcu}$$

(iii) Journey times for buses for the 'with' bus lane situation were calculated from equation 7.1 (Section 7.1.1). This is illustrated with reference to the summary queue length table for the surveys of 4^{th} and 5^{th} February given in Table F6. (Note that these are final queues at the end of each time interval, while the example below uses average queues from the mean of 2 adjacent final queues). Again, considering the Denmark Hill bus lane links (401, 501 and 601):

The maximum number of pcus in the storage area = 17 (Section 7.1).

∴ Any queue in excess of this can be overtaken by buses, subject to the limitations of the bus lane length (458m, or 83 pcus).

The capacity of the link = saturation flow x proportion of green time per cycle
= 2249 x 30/60 = 1125 pcu/hr
= 0.312 pcu/sec

∴ queue vehicles discharge at a rate of 1/0.312
= 3.21 secs/pcu

∴ each pcu a bus overtakes due to the bus lane can be taken to save the bus 3.21 secs.

Queues overtaken in 8 time periods are: 0, 0, 0, 0, 17, 45, 57, 63 = 182 pcus in total

∴ Average queue overtaken by buses = 182/8 = 23 pcus
∴ Average time saved by buses = 23 x 3.21 = 74 seconds

Note: The method used here is approximate although the sources of error (described in Section 7.1.1) are not considered to be significant in this example.

(iv) CONTRAM has been found to predict increased journey times to main road traffic if the bus lane causes the queue to extend across a junction, even though the controlling stop line capacity is maintained. In this example, this was of the order of 17 secs per vehicle for each junction concerned. This is illustrated in Table F4A for the survey of the 6^{th} February on Denmark Hill, where the predicted disbenefit to cars is 6 seconds. This is thought to be a function of the modelling of exit blocking in CONTRAM rather than a true effect 'on street'. The effect of this bias has been estimated and is included in Table F4.

(v) The predicted disbenefits to non-priority traffic arise primarily from the effect of the small reduction in saturation flows assumed (see item 7.1) when the link is oversaturated. They would reduce to zero for main road traffic if setback distances on each bus lane were increased by only 5m.

(vi) A possible bias against the bus lane when modelling the 'with bus lane' situation is referenced in Appendix E, Section 7b. This occurs when queue lengths are less than can fit in the storage area and discharge rates cannot therefore be affected by the bus lane. This bias was considered to be insignificant at these sites as:

- Under these lower traffic intensity conditions, delays are less sensitive to changes in saturation flow which are, in any case, very small in these examples.
- Significant delays occurred in oversaturated conditions when the bias does not occur.

(vii) Side road traffic on Champion Hill and Ferndene Road is predicted to incur significant additional delay due to the bus lane, which causes queues to extend across these minor roads which then suffer reduced capacity. (There must be some uncertainty in the modelling of driver behaviour under these conditions however). Despite this reduction in capacity, CONTRAM predicts that when the bus lane is introduced on Denmark Hill, some drivers will use the Ferndene Road rat-run as shown in Table F6. The maximum predicted increase in flow's is 28 to 116 vehs/hr, which may raise objections in this residential area.

(viii) Results are highly sensitive to saturation flow estimates, the predicted decrease of only around 2% due to the bus lanes is uncertain (e.g. due to uncertainties of queueing behaviour in the setback) but, if it occurred, would negate the benefits of the bus lane.

Further examination of actual saturation flow profiles during typical green phases (Figure F9) reveals sharp reductions in saturation flow with length of green period as the exit becomes progressively blocked. Calculations in Section 7.1 showed that the reduction in saturation flow due to the bus lane would only occur in the last 3 seconds of green - the reduced value of 1800 pcu/hr is in fact higher than currently achieved during this period (Figure F9) and the bus lanes may therefore have no effect at all. These uncertainties reinforce the need for 'before and after' monitoring.

TRAFFICQ

The results of the TRAFFICQ modelling are given in Table F7. The following explanations are relevant:

(i) Journey times were obtained directly from the summary table for each link.

(ii) Journey times for bus were calculated as for CONTRAM above (section (iii)) except that:

- queue lengths expressed in metres in TRAFFICQ had first to be converted to vehicles.
- queue lengths are averaged over 10 equal periods in TRAFFICQ regardless of the time intervals specified for demand.

(iii) Although predicted journey times were close to those observed (see Figure F8) a large variation was evident when TRAFFICQ runs were repeated using different random seeds. This is not unexpected with this stochastic model under oversaturated conditions. Time restricted the number of runs to 3 per survey, but this is clearly insufficient to obtain stable average results. It is possible that 20-30 runs would be required to obtain satisfactory stability, particularly as the change in saturation flows being assessed is so small. Such a level of detailed analysis could not be justified bearing in mind the uncertainties involved (e.g. particularly in saturation flows).

(iv) The results for Champion Park are unexpected and unrealistic in that non-priority vehicles would not be expected to benefit from the bus lane.

(v) The results for the Champion Hill side road are unrealistic and illustrate a problem of TRAFFICQ in that when a continuous queue on a main road stretches across a minor road entry, no vehicles on the minor road are allowed to enter the main stream. (This is in contrast to CONTRAM where incomplete suppression of minor road capacity is assumed.) Thus, if, for example, the main road queue extends past the side road for the last hour of a two hour modelled period, the average journey time given by TRAFFICQ will relate to vehicles discharging in the first hour. This was typical at Champion Hill for the 'with' bus lane case. However, if in the 'without' bus lane case, main road queues dispersed in the last 15 minutes of modelling, the averaged journey time given by TRAFFICQ would include some vehicles which queued for a predicted 45 minutes! Extending the modelling period would give a fairer comparison, but the absolute journey times would still be likely to be grossly overestimated.

(vi) The extent of any bias described as for CONTRAM above (sections (iv) and (vi)) could not be quantified for TRAFFICQ within the overall variability of the results.

7.2 BLAMP

An example of the BLAMP input data for Denmark Hill for the survey of 4th February is given in Table F9, the results of the evaluation of the proposed bus lane on this link being given in the same Table. Modelling has been limited to Denmark Hill as, at Champion Park, there is a high right turning flow into Windsor Walk and Grove Lane (up to 40%) and BLAMP cannot model this effect.

BLAMP was run for each survey using both constant and varying saturation flows as recorded on each day, the latter as illustrated in Figure F5. The latter was found to give predicted journey times closer to those observed, as illustrated in the example in Figure F8, and confirms the advantage in BLAMP of being able to vary the value of any input parameters at any point during the modelling.

Although the effect of the bus lane on side road traffic could not be predicted from BLAMP, the information on queue lengths enabled the frequency of queues extending past side roads to be monitored and the likelihood of traffic diversions to be subjectively assessed. For example, modelling average conditions indicated that main road queues would extend across Champion Hill, approximately between 0830 and 0920 and across Ferndene Roads between 0850 and 0910. However the maximum queue did not reach Sunray Avenue and so, on an average day, traffic diversions onto Ferndene Road would be unlikely.

7.3 Summary

A summary of results from the non-modelling and modelling evaluation procedures described above are given in Table F10. This Table includes the predicted effects of the bus lane on vehicle journey times on the bus lane links (A) and a breakdown of overall (flow weighted) effects on these main links and on side road traffic. The results should be interpreted with close reference to the comments in Sections 7.1 and 7.2 above.

The disbenefits due to the removal of parking on Champion Park could be estimated from the number of vehicles affected and the increase in search and walking time associated with the new parking location. If 50 vehicles per day suffered an increase of 2 minutes, this would give an approximate annual disbenefit of around £1,000.

8. ECONOMIC EVALUATION

The procedures involved in the economic evaluation are summarised in Appendix E, Section 8, and described for the main study sites in Section 9 of the main report. These procedures are similar to those commonly used for the economic evaluation of traffic management schemes and need no further illustration here. The economic evaluation is based mainly on the measurements/predictions of vehicle journey times and this Appendix has therefore concentrated on illustrating the various methods of obtaining these predictions.

9. OTHER EVALUATION CRITERIA

Examples of these are given in Appendix E, Section 9. For the two bus lanes under evaluation here, the factors to be considered within the overall framework are:

(i) The likely increase in traffic on Ferndene Road and (perhaps) neighbouring residential roads (as predicted in 7.1.1. above).

(ii) The inconvenience and (perhaps) loss of business to traders in shops fronting Grove Lane.

(iii) The loss of parking on Champion Park and the effects of its relocation.

(iv) The resources required for enforcement of the new widespread parking restrictions which are required for Champion Park.

10. SCHEME IMPLEMENTATION

Despite the uncertainty of the model predictions as described earlier, the results in Table F10 and preceding tables indicate that both bus lanes are likely to be worthwhile provided exit blocking conditions remain as the key determinant of delay: Denmark Hill is likely to be particularly beneficial while Champion Park is more marginal due to its shorter length, lower levels of 'normal' delay and the need to implement parking restrictions. A full economic evaluation is not intended here, but both bus lanes would give total net benefits using either the modelling or non-modelling evaluation techniques. (The latter, giving the most optimistic estimates, would indicate total delay savings of around £6,000 and £2,000 per annum for the Denmark Hill and Champion Park bus lanes respectively.)

11. 'AFTER' SURVEYS

11.1 Introduction

The predictions of benefits/disbenefits discussed in previous sections are only applicable to conditions at the time of the 'before' surveys. 'Before and After' studies to assess the effectiveness of a scheme should be undertaken as close as possible to each other (subject to the need for a 'settling down' period) so that the effects of changes in traffic conditions can be minimised. In this case, 'before' surveys were conducted in February 1986, while 'after' surveys were not carried out until June 1987 due to delays in implementation of the schemes, which were introduced in April 1987.

Two significantly different sets of conditions were found between the before and after surveys:

(i) Signal staging/timings In the 'before' surveys, the signals were operating to a fixed cycle time of 60 seconds incorporating two fixed stages: Denmark Hill and Champion Park received 26 seconds and 20 seconds of green time respectively. In the 'after' surveys, the fixed cycle time had been increased to 90 seconds to incorporate a demand dependent 'all-red' pedestrian stage. Champion Park received 23 seconds of green time throughout, while Denmark Hill received either 50 seconds or 33 seconds, depending on whether or not the pedestrian stage was called.

In terms of evaluation using computer modelling this form of signal staging/timing cannot be accurately modelled within either TRAFFICQ or CONTRAM unless the pedestrian stage is either regularly or 'never' used. On two of the survey days the pedestrian stage was called during 42 cycles out of 61, while it was called for 60 cycles out of 70 on the other day. Variable use of this sort requires average signal timings to be used which neither represent the situation when there is, nor when there is not, pedestrian demand. BLAMP has more flexibility in this respect, as data inputs can be varied at any time during the modelling.

The effects of the changes in signal stages/timings meant that, on average, the proportion of effective green time available to Champion park fell from 0.35 to 0.27, while that for Denmark

Hill fell from 0.45 to 0.40. These reductions were due to the increased lost time per cycle resulting from the inclusion of the pedestrian stage.

(ii) Exit blocking conditions The need for both bus lanes is largely governed by the continuation of exit blocking conditions. Such conditions may vary due to changes in flow/traffic control at the critical downstream junction(s) or due to changes in flow feeding the downstream 'bottleneck' from the upstream bus lanes. On average over all surveys traffic flows on Denmark Hill and Champion Park fell by 10.5% and 1.2% respectively between the before and after surveys (see Table F11). The relatively large reduction of flow on Denmark Hill could significantly affect the results.

The incidence of exit blocked cycles also varied significantly between surveys as shown in Table F12. On average for both sites, 65% of cycles were blocked during the 'before' surveys while this reduced to 41% for the 'after' surveys. This reduction in exit blocking is reflected in the measured saturation flows listed in Table F13, many of which are seen to be much higher than those listed in Table F3 for the 'before' situation.

On average, saturation flows increased on Denmark Hill between the 'before' and 'after' surveys from 2170 pcu/hr to 2278 pcu/hr, an increase of 5% which was not statistically significant. On Champion Park, the increase was from 2310 pcu/hr to 3148 pcu/hr, or 36%. This large increase in saturation flow on Champion Park was largely due to its stage following the all-red pedestrian stage, during which period the exit was often able to clear. The decrease in exit blocking was clearly not caused by the introduction of the bus lanes, as saturation flows increased on their implementation.

The variation in signal timings and saturation flows between the before and after surveys caused a variation in capacity between the surveys. Average capacities of the two entries, being the product of their saturation flows and proportion of the cycle in which they were effectively green, are given below:

	AVERAGE CAPACITY (pcu/hr)		
	Before	After	Difference (%)
Denmark Hill	977	911	-7
Champion Park	809	850	+5

Thus, capacity on Denmark Hill fell by around 7% between the before and after surveys; this may have contributed to the lower traffic demand on this approach to some extent. In contrast, capacity on Champion Park increased, despite its lower proportion of effective green, due to its increased saturation flow.

11.2 Effects of Bus Lanes

With the variations in traffic conditions and signal control described above, it is very difficult to isolate the effects of the bus lanes. However, a number of relevant analyses have been undertaken:

11.2.1 Saturation Flows of Unblocked Cycles

The effects of the bus lanes on saturation flows, which are normally crucial to overall performance, can only be assessed during cycles not suffering from exit blocking. An indication of these effects is given in Table F14, where measured and predicted results can be compared. The saturation flows in Table F14 were obtained as follows :

(i) Measured, with bus lane

These are average saturation flows as measured on-street for all unblocked fully saturated cycles.

(ii) Measured, without bus lane

These are as (i) but excluding data at the end of each cycle which may have been affected by the bus lane (i.e. flows were excluded after the last vehicle queueing in the nearside lane of the setback at the start of green crossed the stop-line). This is thus a proxy measurement of without bus lane saturation flow; insufficient data was available from the without bus lane surveys due to the increased incidence of exit blocking.

(iii) Predicted, with bus lane

As predicted using TRRL RR67 relationships and the procedure described in Figure 7.3, section 7.

(iv) Predicted, without bus lane

As predicted using TRRL RR67 relationships.

Some reduction in saturation flow was measured at Denmark Hill which may be attributable to the bus lane but the reduction is much less than that predicted. The predicted and average observed saturation flow profiles at Denmark Hill are illustrated in Figure F10. It is clear that the abrupt reduction in saturation flow predicted when the setback had discharged (see Figure 7.3) does not correspond to the gradual reduction observed. The reasons for this could include:

(i) vehicles queueing back into the bus lane when the signals are on red (i.e. violations).
(ii) violation of the end of the bus lane when the signals are on green.

On-site measurements of queue length at the start of each green stage allowed some quantification of item (i) above. On average over all saturated phases, 3.1 violating vehicles were observed to be queueing in the bus lane at the start of the green phase at Denmark Hill. This explains about 35% of the difference between measured and predicted effects of the bus lane on saturation flow (Table F14). Similar measurements at Champion Park showed an average of 2.4 violators of this sort; this would explain some 58% of the difference between measured and predicted effects of the bus lane on saturation flow (Table F14).

A reduction in saturation flow of unblocked cycles due to the bus lane is only important at these sites if this saturation flow is below that due to exit blocking (i.e. the bus lane became the factor controlling capacity). On the day when significant queueing occurred on Denmark Hill (25.6.87) this was not the case as the saturation flow including exit blocked cycles had a maximum value of 2580 pcu/hr (see Table F13, time period 7) which is lower than the 2874 pcu/hr measured for unblocked cycles (see Table F14). The effects of the bus lane on non-priority traffic were therefore irrelevant on this day, reduced capacity downstream of the bus lane link being the main constraint.

11.2.2 Violations

a) Stationary Vehicles

During 6 hours of survey, the Denmark Hill bus lane was 'blocked' at some point by a stationary vehicle for a total of approximately 14 minutes, about a half of this period being caused by ambulances. This caused some reduction in journey time benefit to 3 buses. One parking violation lasting 5 minutes was observed on Champion Park, affecting 1 bus.

b) Moving Vehicles

A summary of the numbers of moving violations of the bus lanes, averaged over all surveys, is given below:

Location		Moving Violations	
		Vehicles per Survey	% of total traffic
Denmark Hill :	downstream 1/3rd of bus lane	193	9.6
Denmark Hill :	mid 1/3rd of bus lane	178	8.9
Champion Park:	whole bus lane	93	6.1

These violations include those that occurred whether or not a queue was present in the lane alongside the bus lane: violations in the absence of a queue were quite high (e.g. 117 such violations were measured in the mid third of the Denmark Hill bus lane during one survey). The extent to which this may reduce as drivers become more used to the bus lane (or if there is police enforcement) is unknown. The overall violation rate on Denmark Hill was about twice that observed on equivalent sites outside London.

11.2.3 Journey Time

Average journey times for priority and non-priority vehicles on each bus lane link are given in Tables F15 and F16 for 15 minute intervals throughout each survey. These results are illustrated in Figures F11 to F13. Equivalent results for the no bus lanes situation are given in Tables F2A and F2B. The effects on buses and non-priority vehicles are considered separately below :

(i) Bus journey time savings

A clearer comparison of bus and non priority vehicle journey times is obtained if the effects of bus stops are removed from the bus journey times. This also allows direct comparison with CONTRAM predictions. The effects of bus stops can be assumed to be approximately equal to the difference in journey time between buses and non-priority vehicles in the without bus lane situation (i.e. with no bus stops, these average journey times should be similar). This average difference was 61 seconds and 50 seconds for Denmark Hill and Champion Park respectively (from Tables F2A and F2B). Subtracting these figures from the measured bus journey times in Tables F15 and F16 (averaged over 3 days) would give average bus journey times with the bus lane (excluding stops) of 103 seconds and 129 seconds per bus for Denmark Hill and Champion Park respectively.

These results are close to those obtained using CONTRAM output (Table F4) - in which bus stopped time is excluded and 'cruise' speeds are considered equal - which average 83 secs and 102 secs for the two bus lanes. The discrepancies of 20 secs and 27 secs at each site are likely to be largely due to the introduction of the pedestrian stage, which increased the average red time on Denmark Hill and Champion Park by 19 secs and 27 secs respectively.

If average bus stopped times are subtracted from measured bus journey times in Tables F15 and F16, the average reductions in journey time for buses (compared to non-priority traffic) due to the bus lanes on the survey days are : -

Location	Survey Date	Average Reduction in Journey Time per Bus (secs)
Denmark Hill	23.6.87	8+
	24.6.87	11+
	25.6.87	154*
	Average	58
Champion Park	16.6.87	5+
	17.6.87	-18*
	18.6.87	-7+
	Average	-7

+ insignificant @ 5% level
* significant @ 5% level

These reductions would be actual journey time savings for buses due to the bus lanes provided the bus lanes caused no additional delay to non-priority traffic. It is considered that, apart from the additional 2 secs/vehicle journey time to non-priority vehicles caused by 'queue displacement' (see section 5.2) this condition was satisfied for these bus lanes, as exit blocking was the key parameter controlling their journey time.

These estimates of bus journey time savings due to the bus lanes are therefore considered to be more appropriate than the savings calculated by subtraction of the with and without bus journey times, which would give average 'savings' of 93 seconds/bus and 11 seconds/bus for Denmark Hill and Champion Park respectively. Theselatter figures would represent the combined savings due to the bus lanes, changes in junction control and changes in exit blocking conditions, these three effects not being able to be separated.

Extending the arguments above the results illustrate that buses on Denmark Hill achieved average delay savings due to the bus lane of 154 secs on one survey day out of three, with small statistically insignificant savings on the other two days. (These savings might have been higher but for the 10.5% reduction in traffic flow on this link, although this effect is difficult to quantify due to the variability in the journey time/flow relationship.) There is clearly likely to be considerable between-day variation in bus delay savings on this link. The results above for Champion Park are perverse in that the bus lane should not cause buses to suffer more delay relative to cars as shown by the negative 'savings' on two days. This can occur if the bus lane increases car speeds, reduces bus speeds, causes queues to extend upstream of the bus lane (thus impeding buses) and/or if bus stopped times vary. None of these occurrences are thought likely but, as most of the differences are small and statistically insignificant, further investigation has not been undertaken. With the increase in capacity for the Champion Park link, delay savings to buses would be expected to be small at best.

(ii) Non-priority vehicle disbenefits

The CONTRAM modelling of the with bus lane situation, based on data collected during the without bus lane surveys, indicated predicted average disbenefits to non-priority traffic due to the Denmark Hill and Champion Park bus lanes of some 25 and 6 seconds per vehicle respectively (see Table F4). These cannot be validated, however, as the with bus lane measurements indicated reduced average journey times for non-priority vehicles at the two bus lanes of 14 and 3 seconds per vehicle (Tables F15/16 compared to Tables F2A/B). These savings are undoubtedly due to the different junction control and exit blocking condition occuring during the two sets of surveys rather than to any (perverse) effects of the bus lanes.

Estimation of the effects of the bus lanes on non-priority traffic is considered to be best based on the analysis of saturation flows described in Section 11.2.1. This indicated that, although the Denmark Hill bus lane caused some reduction in saturation flow during unblocked cycles, the resulting saturation flow was still higher than that during exit blocked cycles which predominated. Also the predicted reduction in saturation flow due to the bus lanes was substantially higher than observed for reasons set out in Section 11.2.1. The CONTRAM predictions of disbenefits to non-priority traffic are therefore likely to be incorrect, a value of 2 secs/vehicle reflecting 'queue displacements' only (see Section 5.2) being probably most appropriate. The only scenario where the effects of the bus lane could be significant is therefore if exit blocking suddenly ceased and the queue on Denmark Hill would then take longer to dissipate with the bus lane. This was not observed in practice.

11.2.4 Traffic Re-Assignment

Traffic flows on Denmark Hill reduced by 10.5% between the before-and-after surveys, a trend which is not reflected in London traffic as a whole. It must therefore be assumed that traffic has re-assigned to alternative routes. It cannot be assumed, however, that this re-assignment is due to increased queues caused by the new bus lane, as other factors could include a general increase in congestion through Camberwell, the reduction in capacity at the Champion Park junction due to the introduction of the pedestrian stage and so on.

Local re-assignment of Denmark Hill traffic onto residential roads, emerging at Ferndene Road, was measured, however. Surveys were undertaken to quantify this effect, with the main results being given in Table F17. Item 1 in Table F17 shows the measured flows on Ferndene Road under 'normal' conditions (i.e. when the main road was not blocked). These flows may be compared with those on a different survey day (item 3) when queues on Denmark Hill extended upstream of Ferndene Road, as shown in item 2. These comparisons reveal a clear re-assignment of traffic onto Ferndene Road when queues are longest on Denmark Hill (e.g. in time interval 6). This re-assignment is attributable to the bus lane as queues on Denmark Hill would not have extended past Ferndene Road were there no bus lane.

Items 4 and 5 in Table F17 show CONTRAM's predicted traffic re-assignment onto Ferndene Road due to the Denmark Hill bus lane based on data collected during the before surveys. Re-assignment predicted by CONTRAM (item 5) is of the same order as that observed (item 3) for equivalent queue lengths on Denmark Hill (items 2 and 4).

11.3 MODELLING

The purpose of computer modelling at these bus lane sites was to predict the effects of introducing the bus lanes on vehicle journey times and associated parameters. The 'after' surveys were intended to assess the validity of these predictions, but this has largely been impractical due to the changed traffic and junction control characteristics.

A key element in modelling the effects of a bus lane is the predicted effect of the bus lane on junction saturation flow. This prediction based on the 'before' data is not now valid due to the changed exit blocking conditions, and current measurements do not allow the effects of the bus lane to be distinguished from those due to exit blocking. (This would require current measurements in the 'without' bus lane situation.) The effects of the bus lane during unblocked cycles can be determined (see Section 11.2.1 above) but this is unrepresentative of overall operating conditions, and validation is not therefore possible. Modelling the current situation is not therefore considered to be a worthwhile exercise within the objectives of this research and has not been undertaken.

Nevertheless, the installation of a bus lane under changed conditions from those originally envisaged when it was designed would warrant a re-evaluation which could include computer modelling as discussed in Appendix E.

11.4 SUMMARY

1. There have been significant changes in traffic and junction control conditions between the before and after surveys at Denmark Hill and Champion Park (section 11.1) which preclude a wholly effective validation of the evaluation procedure. Further modelling to attempt to reflect existing conditions is not

thought worthwhile as it is not possible to distinguish between the effects of the bus lane and those of exit blocking under normal operating conditions, and validation would also not be possible. Nevertheless, re-evaluation would be justified in practice due to these changed conditions.

Individual elements of the evaluation procedure have been assessed, however, as described below.

2. Saturation flows on Denmark Hill and Champion Park (at their junction) during cycles unaffected by exit blocking would be predicted to be reduced by some 22% and 17% respectively due to the bus lanes with their selected setback lengths. Observations indicated these reductions to be only 6% and 0% respectively; around a half of these differences between prediction and observation were found to be due to moving violations at the bus lanes. The remaining discrepancies are unexplained.

3. Stationary vehicle violations of the bus lanes were negligible at both sites, but moving vehicle violations were significant, varying between 6.1% and 9.6% of total traffic. The moving violation rate at Denmark Hill was around twice that observed at similar sites outside London. Violations of the downstream end of the bus lanes were most noticeable - this phenomena was often responsible for maintaining junction capacity which may otherwise have been reduced during non blocked cycles due to the relatively short setbacks to the bus lanes.

4. Re-assignment of some Denmark Hill traffic onto residential roads, emerging in Ferndene Road was predicted by CONTRAM as an effect of the bus lane under certain conditions. Similar conditions were observed during one of the after surveys, and similar levels of re-assignment were measured as had been predicted by the model.

5. Surveys showed that buses on Champion Park were not benefitting significantly from the bus lane, in terms of delay savings, whereas, on one of the three surveyed days, buses on Denmark Hill gained considerably (some 154 secs/bus on average). On this day, observed saturation flows were below those predicted, due to severe exit blocking conditions, and the bus lane itself was therefore having no detrimental affect on capacity: The average saving of 154 secs/bus was therefore a true benefit of the bus

lane. Clearly there are large between-day variations, and it is not unlikely that the Champion Park bus lane could be beneficial on other occasions.

On days when exit blocking is less serious the Denmark Hill bus lane could cause a small disbenefit to non-priority traffic due to the small (measured) reduction in saturation flow caused by the short setback relative to the new green times. However, on these occasions little queueing would be expected with current traffic demand.

TABLE F1 : CLASSIFIED TRAFFIC COUNTS — BEFORE SURVEYS

A. DENMARK HILL[1] — 4th/5th February 1986

VEHICLE* TYPE	TRAFFIC COUNTS IN 15 MINUTE INTERVALS FROM 0730 HRS								AVERAGE (VEHS/HR)	% TOTAL TRAFFIC
	1	2	3	4	5	6	7	8		
Cars/Light Goods	242	212	230	253	298	259	263	258	1008	89.4
Medium Goods	6	5	7	3	7	6	4	7	23	2.0
Heavy Goods	0	1	1	0	0	1	0	1	2	0.2
Buses/Coaches	4	5	7	5	2	6	3	4	18	1.6
Motorcycles	9	13	10	12	18	13	10	12	49	4.2
Pedal Cycles	4	5	3	7	12	12	8	7	29	2.6
Total Vehicles	265	241	258	280	337	297	288	289	1128	100
Total pcu's	263	238	261	274	322	290	281	285	1107	100

B. CHAMPION PARK[1]

VEHICLE* TYPE	TRAFFIC COUNTS IN 15 MINUTE INTERVALS FROM 0730 HRS								AVERAGE (VEHS/HR)	% TOTAL TRAFFIC
	1	2	3	4	5	6	7	8		
Cars/Light Goods	160	171	170	199	188	170	135	108	650	84.1
Medium Goods	8	7	10	5	8	6	7	7	29	3.8
Heavy Goods	1	2	0	0	0	0	0	1	2	0.3
Buses/Coaches	6	3	5	4	4	5	5	5	19	2.5
Motorcycles	16	12	10	12	17	15	12	8	51	6.5
Pedal Cycles	4	2	5	6	9	8	5	5	22	2.8
Total Vehicles	195	197	200	226	226	204	164	134	773	100
Total pcu's	195	197	202	222	219	195	161	145	768	100

* Cars/light goods: vehicles with 3 or 4 wheels; pcu factor = 1
Medium goods : vehicles with > 4 wheels but 2 axles; pcu factor = 1.5
Heavy goods : vehicles with > 2 axles; pcu factor = 2.3
Buses/coaches pcu factor = 2.0
Motorcyles pcu factor = 0.4
Pedal cyles pcu factor = 0.2

1 at stop line at downstream end of bus lane link

Signal Settings: Cycle time, C = 60 secs (fixed)
Green plus amber period, G (Denmark Hill) = 29 secs "
Green plus amber period, G (Champion Park) = 23 secs "

TABLE F2 : VEHICLE JOURNEY TIMES

A. DENMARK HILL

BEFORE SURVEYS

SURVEY DATE	PARAMETER	VEHICLE TYPE	AVERAGE JOURNEY TIME (SECS/VEH)								
			TIME INTERVAL (15 MINS FROM 0730 HRS)								WHOLE SURVEY
			1	2	3	4	5	6	7	8	
4th Feb	Journey time	Buses	66	262	156	278	267	230	152	-	202
	Sample size		2	2	5	1	2	4	3	0	
	Standard Deviation		4	8	44	0	95	27	41	-	
	Journey time	Non-priority	66	176	158	146	255	285	126	-	173
	Sample size		3	5	3	5	13	9	12	0	
	Standard Deviation		31	55	21	76	88	100	24	-	
5th Feb	Journey time	Buses	138	108	99	184	223	148	404	309	302
	Sample size		3	2	4	4	2	3	2	3	
	Standard Deviation		24	53	27	102	116	7	51	8	
	Journey time	Non-priority	79	310	77	125	158	109	222	244	166
	Sample size		6	3	7	11	9	10	11	8	
	Standard Deviation		9	48	6	49	29	23	81	82	
6th Feb	Journey time	Buses	130	203	148	281	301	338	349	367	265
	Sample size		4	3	7	3	4	6	2	4	
	Standard Deviation		12	35	28	39	12	67	48	48	
	Journey time	Non-priority	82	120	-	279	313	347	297	282	246
	Sample size		3	8	0	9	11	10	10	6	
	Standard Deviation		7	88	-	31	103	51	37	19	
4th&5th	Journey time	Buses	102	185	128	231	245	189	278	309	208
	Journey time	Non-priority	73	243	118	136	207	197	174	244	174

TABLE F2 : (Continued)

B. CHAMPION PARK

SURVEY DATE	PARAMETER	VEHICLE TYPE	AVERAGE JOURNEY TIME (SECS/VEH)								
			TIME INTERVAL (15 MINS FROM 0730 HRS)								WHOLE SURVEY
			1	2	3	4	5	6	7	8	
4th Feb	Journey time	Buses	141	139	145	193	224	202	185	158	173
	Sample size		6	4	5	3	2	5	3	4	
	Standard Deviation		41	47	37	43	46	48	46	26	
	Journey time	Non-priority	66	82	87	80	216	160	148	113	119
	Sample size		13	14	16	17	13	10	14	7	
	Standard Deviation		22	30	23	25	54	20	33	18	
5th Feb	Journey time	Buses	160	191	132	176	212	244	194	120	179
	Sample size		5	2	6	3	3	3	6	3	
	Standard Deviation		36	62	25	16	40	21	45	20	
	Journey time	Non-priority	101	90	100	134	174	192	174	88	132
	Sample size		13	14	18	12	19	9	5	7	
	Standard Deviation		28	21	23	29	37	16	49	23	
6th Feb	Journey time	Buses	152	141	169	196	280	237	290	287	219
	Sample size		3	1	5	3	3	2	1	2	
	Standard Deviation		60	0	33	22	35	19	0	45	
	Journey time	Non-priority	78	96	107	174	149	228	216	213	158
	Sample size		1	14	20	18	13	19	8	7	
	Standard Deviation		0	29	29	33	24	27	29	43	
4th&5th	Journey time	Buses	151	165	139	184	218	223	189	139	176
	Journey time	Non-priority	84	86	93	107	195	176	161	101	126

TABLE F3 : SUMMARY OF MEASURED SATURATION FLOWS AND LOST TIMES

A. DENMARK HILL

BEFORE SURVEYS

DATE	TIME* PERIOD	SATURATION FLOW** (PCU/HR)	se	ss	LOST TIME (SECS)** INITIAL	ss	END	ss
4th Feb, '86	1	2442,	84,	39	-0.4,	15	-0.9,	5
	2	1901,	87,	45	-1.0,	15	-1.0,	12
	3	2397,	159,	44	-0.5,	15	0.2,	13
	4	1883,	160,	45	-3.0,	15	0.6,	14
	5	2015,	222,	45	-0.8,	15	-0.3,	15
	6	2357,	80,	45	-1.3,	15	-0.4,	15
	7	2360,	133,	45	-1.5,	15	0.6,	15
	8	2201,	151,	44	-1.9,	15	1.0,	12
5th Feb, '86	1	2278,	219,	33	-1.4,	15	-1.3,	6
	2	2331,	344,	21	-1.3,	15	-1.5,	2
	3	2694,	144,	28	-0.4,	15	-0.9,	1
	4	2039,	129,	44	-1.4,	15	0.1,	13
	5	2609,	174,	45	-1.0,	15	0.3,	14
	6	2589,	146,	45	-0.3,	15	-0.3,	14
	7	1791,	169,	45	-2.8,	15	-0.1,	15
	8	2093,	157,	45	-2.4,	15	0.1,	14
6th Feb, '86	1	2073,	278,	35	-1.9,	15	0.7,	7
	2	2117,	124,	31	-1.3,	15	3.3,	2
	3	1977,	133,	44	-1.7,	15	1.0,	12
	4	1765,	119,	45	-2.0,	15	3.0,	15
	5	2167,	138,	45	-1.1,	15	1.9,	15
	6	1847,	136,	45	-0.9,	15	1.2,	15
	7	2183,	115,	45	-2.2,	15	1.8,	14
	8	1968,	121,	45	-1.9,	15	-0.4,	15

* Consecutive 15 minute periods
** se = standard error
ss = sample size

TABLE F3 : (Continued)

B. CHAMPION PARK

BEFORE SURVEYS

DATE	TIME* PERIOD	SATURATION FLOW** (PCU/HR)	se	ss	LOST TIME (SECS)** INITIAL	ss	END	ss
4th Feb, '86	1	2370,	673,	12	- 1.4,	13	2.7,	2
	2	2546,	905,	14	- 0.9,	14	4.4,	5
	3	2700,	626,	16	- 0.9,	13	4.7,	6
	4	2483,	487,	18	- 1.0,	13	4.0,	6
	5	1854,	440,	21	- 1.3,	15	4.2,	10
	6	2310,	611,	14	- 0.2,	15	3.8,	4
	7	1913,	834,	8	- 1.6,	15	3.1,	1
	8	2126,	1407,	7	- 1.1,	15	2.5,	2
5th Feb, '86	1	3060,	1599,	8	- 0.2,	12	3.6,	1
	2	2587,	1360,	9	- 1.3,	14	5.0,	2
	3	2625,	3253,	4	- 1.5,	11	3.6,	1
	4	2464,	684,	15	- 2.1,	15	4.0,	3
	5	2255,	740,	12	- 2.4,	15	4.5,	3
	6	2328,	1072,	10	- 2.2,	15	3.5,	2
	7	1452,	944,	10	- 6.8,	15	4.4,	4
	8	2854,	1884,	7	- 0.2,	14	-	0
6th Feb, '86	1	2550,	582	12	- 0.9,	15	-	0
	2	2367,	994	9	- 0.8,	15	3.5,	2
	3	1971,	510	14	- 2.2,	14	4.1,	3
	4	2040,	249	21	- 2.5,	15	4.6,	4
	5	2182,	297	19	- 2.0,	15	4.5,	6
	6	2030,	239	25	- 1.9,	15	4.5,	11
	7	2143,	429	21	- 2.0,	15	4.4,	9
	8	2234,	209	21	- 1.3,	15	3.9,	6

* Consecutive 15 minute periods
** se = standard error
ss = sample size

TABLE F4 : JOURNEY TIME PREDICTIONS FROM CONTRAM

A. BUS LANE LINKS

DATE	LOCATION	AVERAGE JOURNEY TIMES (SECS/VEH)			BENEFIT (SECS/VEH)		
		WITH BUS LANE		WITHOUT BUS LANE **	CARS*		BUSES*
		CARS*	BUSES	(ALL TRAFFIC)	A	B	
4th Feb.	Denmark Hill	239	80	201 (173)	-38	-21	121
5th Feb.		191	80	144 (166)	-47	-30	64
6th Feb.		138	88	132 (246)	-6	0	44
4th&5th		210	94	168 (174)	-42	-25	74
4th Feb.	Champion Pk	100	98	98 (119)	-2	-2	0
5th Feb.		130	100	115 (132)	-15	-15	15
6th Feb.		113	108	113 (158)	0	0	5
4th&5th		108	99	102 (126)	-6	-6	3

B. SIDE ROADS

DATE	LOCATION	AVERAGE JOURNEY TIMES (SECS/VEH)		BENEFIT (SECS/VEH)
		WITH BUS LANE	WITHOUT BUS LANE	
4th Feb.	Champion Hill	202	147	-55
5th Feb.		178	63	-115
6th Feb.		77	60	-17
4th&5th		189	94	-95
4th Feb.	Ferndene Rd	136	51	-85
5th Feb.		81	53	-28
6th Feb.		52	52	0
4th&5th		108	53	-55
4th Feb.	Sunray Ave.	37	37	0
5th Feb.		37	37	0
6th Feb.		36	36	0
4th&5th		37	37	0

TABLE F4 : (Continued)

C. OVERALL NETWORK

DATE	AVERAGE JOURNEY TIME FOR NON-PRIORITY VEHICLES (VEH.HRS)		BENEFITS[1] (VEH.HRS)		
			CARS*		
	WITH BUS LANE	WITHOUT BUS LANE	A	B	BUSES
4th Feb.	226	210	-16	-11	1.2
5th Feb.	223	201	-22	-17	0.8
6th Feb.	173	201	-2	-2	0.5
4th & 5th Feb.	221	203	-18	-13	0.8

[1] Cars column A results taken from CONTRAM. Column B results are as A but corrected for bias described in item 7.1.1. (iv).

NOTE : These results exclude the small disbenefit to cars* (around 2 secs/veh) due to the overtaking effect of buses.

* and other non-priority traffic
** measured results given in brackets

TABLE F5 : AVERAGE DELAYS AND QUEUES PREDICTED FROM CONTRAM

Link-by-Link Values - Average Queue Times (Secs)

BASED ON BEFORE DATA

Link No. / Time Intv	1	2	3	4	5	6	7	8	9	10
715	730	745	800	815	830	845	900	915	930	1030
101S	7	8	8	8	8	8	8	8	8	7
102S	12	12	12	12	12	12	12	12	12	12
201U	0	0	0	0	0	0	0	0	0	0
202U	0	0	0	0	0	0	0	0	0	0
301U	0	0	0	0	0	0	0	0	0	0
302G	3	3	3	3	4	5	5	5	5	4
401U	0	0	0	0	0	0	0	0	0	0
402G	9	10	9	10	10	11	11	10	10	6
501U	0	0	0	0	0	0	28	59	77	15
502G	9	10	9	10	10	12	143	109	40	9
601S	13	29	30	29	42	110	183	183	183	106
602S	14	29	35	39	53	77	71	39	22	12
701S	7	12	12	12	13	14	13	11	10	7
702S	12	12	12	12	12	12	12	12	12	12
801U	0	0	0	0	0	0	0	0	0	0

Link-by-Link Values - Final Queues (PCUs)

Link No. / Time Intv	1	2	3	4	5	6	7	8	9	10
	730	745	800	815	830	845	900	915	930	1030
101S	3	3	3	3	3	3	3	3	3	0
102S	0	0	0	0	0	0	0	0	0	0
201U	0	0	0	0	0	0	0	0	0	0
202U	0	0	0	0	0	0	0	0	0	0
301U	0	0	0	0	0	0	0	0	0	0
302G	0	0	0	0	1	1	1	1	1	0
401U	0	0	0	0	0	0	0	0	0	0
402G	0	0	0	0	0	0	0	0	0	0
501U	0	0	0	0	0	0	16	20	28	0
502G	0	0	0	0	0	0	5	2	1	0
601S	6	10	7	9	15	52	56	56	56	0
602S	5	7	8	9	15	21	12	5	4	0
701S	5	5	5	5	6	6	5	4	4	0
702S	0	0	0	0	0	1	1	0	0	0
801U	0	0	0	0	0	0	0	0	0	0

TABLE F6 : EXAMPLE OF PREDICTED TRAFFIC RE-ASSIGNMENT

BASED ON BEFORE DATA

PARAMETER	LINK(S) *	WITH/ WITHOUT BUS LANE	CONSECUTIVE TIME INTERVALS OF 15 MINS							
			1	2	3	4	5	6	7	8
Arrival Flow (vehs/hr)	401	Without	1040	960	1108	1124	1268	1216	1140	1124
		With	1040	960	1108	1124	1264	1172	1052	1040
Queue Length (vehs)	401	Without	0	0	0	0	0	0	0	0
		With	0	0	0	0	8	30	50	58
Journey Times (secs/veh)	301 &	Without	41	41	41	41	41	41	41	41
	401	With	41	41	41	41	66	147	222	247
Arrival Flow (vehs/hr)	402	Without	24	24	28	28	32	32	28	28
		With	24	24	28	28	32	76	116	112
Queue Length (vehs)	402	Without	0	0	0	0	0	0	0	0
		With	0	0	0	0	0	3	7	8
Journey Times (secs/veh)	201 &	Without	58	57	58	58	59	59	58	58
	402	With	58	57	58	58	75	255	283	311

* See Figure F7A

TABLE F7 : AVERAGE JOURNEY TIME PREDICTIONS FROM TRAFFICQ

A. BUS LANE LINKS

BASED ON BEFORE DATA

DATE	BUS LANE	RANDOM SEED	JOURNEY TIMES (SECS/VEH)			BENEFIT (SECS/VEH)	
			WITH BUS LANE		WITHOUT ALL TRAFFIC		
			CARS*	BUSES		CARS*	BUSES
4th Feb.	D. Hill	7777	347	102	183		
		8888	252	102	165		
		9999	338	97	216		
		Aver.	312	100	188	-124	88
5th Feb.	D. Hill	7777	210	101	254		
		8888	250	107	196		
		9999	263	106	242		
		Aver.	241	105	231	-10	126
6th Feb.	D. Hill	7777	88	90	97		
		8888	96	83	83		
		9999	95	91	101		
		Aver.	93	88	94	1	6
4th&5th	D. Hill	7777	225	119	245		
		8888	189	96	166		
		9999	175	102	178		
		Aver.	196	106	196	0	91
4th Feb.	C. Park	7777	147	97	161		
		8888	133	101	152		
		9999	171	121	204		
		Aver.	150	106	172	22	66
5th Feb.	C. Park	7777	193	112	203		
		8888	183	134	221		
		9999	227	156	256		
		Aver.	201	134	227	26	93
6th Feb.	C. Park	7777	109	98	108		
		8888	135	98	141		
		9999	119	97	141		
		Aver.	121	98	130	9	32
4th&5th	C. Park	7777	190	121	226		
		8888	167	145	241		
		9999	151	124	227		
		Aver.	169	130	231	62	101

TABLE F7 : (Continued)

B. SIDE ROADS

DATE	LOCATION	JOURNEY TIME** (SEC/VEH)								BENEFIT OF BUS LANE
		WITH BUS LANE				WITHOUT BUS LANE				
4th Feb.	Champion Hill	67	63	65	65	295	196	61	184	119
5th Feb.		63	64	66	64	288	188	258	245	181
6th Feb.		60	60	60	60	62	63	57	61	1
4th&5th		455	235	188	293	59	191	120	123	-170
4th Feb.	Ferndene Road	88	67	71	75	65	68	67	67	-8
5th Feb.		61	71	72	68	75	64	75	71	3
6th Feb.		67	59	68	65	68	64	67	66	1
4th&5th		69	67	69	68	65	72	76	71	3
4th Feb.	Sunray Ave.	38	35	36	36	29	29	29	29	-7
5th Feb.		38	37	40	38	29	29	30	29	-9
6th Feb.		29	32	31	31	28	28	28	28	-3
4th&5th		38	37	37	37	29	34	30	31	-6

C. OVERALL NETWORK

DATE	JOURNEY TIME FOR NON-PRIORITY VEHICLES** (VEH.HRS)								BENEFIT (VEH.HRS)	
	WITH BUS LANE				WITHOUT BUS LANE				CARS*	BUSES
4th Feb.	201	154	191	182	146	135	164	148	-34	1.6
5th Feb.	162	171	188	174	184	169	195	183	9	2.2
6th Feb.	90	98	94	94	92	96	101	96	2	0.4
4th&5th	173	151	142	155	178	163	159	167	12	2.0

1 Benefits are only given for the average of 3 runs using different random seeds. Comparisons of individual runs would be invalid as any change in input data (e.g. saturation flow) also effects the random seed.

NOTE : These results exclude the small disbenefit to cars* (around 2 secs/veh due to the overtaking effect of buses

* and other non-priority traffic

** The 4 figures represent (in order) three separate runs using different random seeds and the average of these runs.

TABLE F8 EXAMPLE OF PREDICTED QUEUE LENGTHS AND JOURNEY TIMES FROM TRAFFICQ FOR BUS LANE LINKS

VARIATI.N OF QUEUE LENGTH WITH TIME (% OF SIMULATION PERIOD)

FOR BUS LANE SUNRAY-FERN LINK NO. 13 LINK LENGTH = 422M

ALL VEHICLES MEAN LENGTH(M)	TIME	RIGHT TURNERS MEAN LENGTH(M)	TIME	FILTER VEHICLES MEAN LENGTH(M)	TIME
2	0 TO 10	0	0 TO 10	0	0 TO 10
3	11 TO 20	0	11 TO 20	0	11 TO 20
3	21 TO 30	0	21 TO 30	0	21 TO 30
3	31 TO 40	0	31 TO 40	0	31 TO 40
2	41 TO 50	0	41 TO 50	0	41 TO 50
3	51 TO 60	0	51 TO 60	0	51 TO 60
4	61 TO 70	0	61 TO 70	0	61 TO 70
6	71 TO 80	0	71 TO 80	0	71 TO 80
40	81 TO 90	0	81 TO 90	0	81 TO 90
96	91 TO	0	91 TO	0	91 TO

MEAN = 16.2 MEAN = 0.0 MEAN = 0.0

FOR BUS LANE FERN-CHMP HILL LINK NO. 15 LINK LENGTH = 154M

ALL VEHICLES MEAN LENGTH(M)	TIME	RIGHT TURNERS MEAN LENGTH(M)	TIME	FILTER VEHICLES MEAN LENGTH(M)	TIME
3	0 TO 10	0	0 TO 10	0	0 TO 10
3	11 TO 20	0	11 TO 20	0	11 TO 20
3	21 TO 30	0	21 TO 30	0	21 TO 30
2	31 TO 40	1	31 TO 40	0	31 TO 40
3	41 TO 50	0	41 TO 50	0	41 TO 50
22	51 TO 60	0	51 TO 60	0	51 TO 60
92	61 TO 70	0	61 TO 70	0	61 TO 70
131	71 TO 80	0	71 TO 80	0	71 TO 80
139	81 TO 90	0	81 TO 90	0	81 TO 90
139	91 TO	0	91 TO	0	91 TO

MEAN = 53.7 MEAN = 0.1 MEAN = 0.0

FOR BUS LANE CH HILL-LIGHTS LINK NO. 19 LINK LENGTH = 154M

ALL VEHICLES MEAN LENGTH(M)	TIME	RIGHT TURNERS MEAN LENGTH(M)	TIME	FILTER VEHICLES MEAN LENGTH(M)	TIME
39	0 TO 10	0	0 TO 10	0	0 TO 10
42	11 TO 20	0	11 TO 20	0	11 TO 20
53	21 TO 30	0	21 TO 30	0	21 TO 30
68	31 TO 40	0	31 TO 40	0	31 TO 40
117	41 TO 50	0	41 TO 50	0	41 TO 50
140	51 TO 60	0	51 TO 60	0	51 TO 60
147	61 TO 70	0	61 TO 70	0	61 TO 70
147	71 TO 80	0	71 TO 80	0	71 TO 80
147	81 TO 90	0	81 TO 90	0	81 TO 90
147	91 TO	0	91 TO	0	91 TO

MEAN = 104.7 MEAN = 0.0 MEAN = 0.0

SUMMARY OF MEAN LINK TIMES (IN SECONDS)
======================================

LINK	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
TIME	35	25	29	0	33	37	0	0	65	0	18	0	45	0	60	0	57

LINK	18	19	20	21	22	23	24	25	26	27	28	29	30
TIME	74	132	0	88	0	138	0	0	0	0	21	26	23

TABLE F9 : BLAMP MODELLING OF DENMARK HILL, 04.02.86

A. DATA INPUTS

Setback (m)	47
Cycle Time (secs)	60
Effective Green Time (secs)	30
Bus Flows (pcu/hr)	36
Bus Lane Length (m)	458 (0 for without situation)
Link Length (m)	800
Flow Profile Interval (mins)	15
No. of Intervals	8
Total Flows (pcu's/hr)	1018, 929, 1088, 1094, 1256, 1185 1116, 1091
Vehicle Queueing Length (m)	5.5
Saturation flows (da_1, da_2, db_2, d_c)*	1098, 1098, 1800, 1800

* See example in Appendix B

B. RESULTS

DATE	CONDITION	AVERAGE JOURNEY TIMES (SECS/VEH)			BENEFIT (SECS/VEH)	
		WITH BUS LANE		WITHOUT BUS LANE		
		CARS*	BUSES		CARS*	BUSES
4th Feb.	Const. sat^n flows	142	75	140	-2	65
5th Feb.		114	74	111	-3	37
6th Feb.		150	88	147	-3	59
4th&5th		128	75	125	-3	50
4th Feb.	varying sat^n flows	215	75	211	-4	136
5th Feb.		128	74	125	-3	51
6th Feb.		156	83	153	-3	70
4th&5th		172	75	168	-4	93

* and other non-priority traffic

TABLE F10 : SUMMARY OF RESULTS

A. BUS LANE LINKS

BASED ON BEFORE DATA

LOCATION	PREDICTION METHOD	JOURNEY TIMES (SECS/VEH)			BENEFIT (SECS/VEH)	
		WITH BUS LANE		WITHOUT BUS LANE	CARS*	BUSES*
		CARS*	BUSES			
Denmark Hill	Non-modelling	176	105	174	-2	69
	CONTRAM**	195	94	168	-25	74
	TRAFFICQ	198	106	196	-2	91
	BLAMP	172	75	168	-4	93
Champion Park	Non-modelling	126	105∇	125	-1	20
	CONTRAM	108	99	102	-6	3
	TRAFFICQ	169	130	231	62	101
	BLAMP	nm	nm	nm	nm	nm

B. OVERALL NETWORK (BASED ON CONTRAM RESULTS)

LOCATION	AVERAGE JOURNEY TIME FOR NON-PRIORITY VEHICLES (VEH.HRS)		BENEFITS (VEH.HRS)	
	WITH BUS LANE	WITHOUT BUS LANE	CARS*	BUSES
OVERALL NETWORK	216	203	-13	0.8
BUS LANE LINKS	155	144	-11	0.8
SIDE ROADS, ETC	61	59	-2	0

∇ estimated
nm not modelled
* and other non-priority vehicles
** allowance made for blocking back bias as described in item 7.1.1. (iv)

NOTE: 1. These results are based on combined data for surveys on 4th and 5th Feb, 1986.
2. 2 seconds per vehicle has been added to the predicted journey time for cars for CONTRAM and TRAFFICQ for the with bus lane situation to allow for the overtaking effect of buses which is not reflected in the modelling as calculated in item 5.2.

TABLE F11 : TRAFFIC COUNTS BEFORE AND AFTER

TIME INTERVAL	TRAFFIC COUNT * (VEHS/HOUR)			
	DENMARK HILL		CHAMPION PARK	
	BEFORE	AFTER	BEFORE	AFTER
7.30-7.45	1060	991	780	764
7.45-8.00	964	1017	788	772
8.00-8.15	1032	963	800	780
8.15-8.30	1120	960	904	888
8.30-8.45	1348	1084	904	800
8.45-9.00	1188	1015	816	724
9.00-9.15	1152	1079	656	692
9.15-9.30	1156	973	536	680
Average	1126	1010	773	763

* Average of survey days

TABLE F12 : PERCENTAGE OF EXIT BLOCKED CYCLES PER SURVEY

SURVEY		PERCENTAGE OF EXIT BLOCKED CYCLES	
TYPE	DATE	DENMARK HILL	CHAMPION PARK
BEFORE	4.2.86	74	63
BEFORE	5.2.86	68	52
BEFORE	6.2.86	74	55
BEFORE	AVERAGE	72	57
AFTER*	16/23.6.87	50	41
AFTER*	17/24.6.87	36	26
AFTER*	18/25.6.87	82	12
AFTER*	AVERAGE	56	26

* Champion Park and Denmark Hill were surveyed on consecutive weeks.

TABLE F13 : SUMMARY OF MEASURED SATURATION FLOWS — AFTER SURVEYS

DATE*	TIME PERIOD**	SATURATION FLOW (pcu/hr)***	
		DENMARK HILL	CHAMPION PARK
16/23.6.87	1	2255, 166, 56	2248, 260, 30
	2	2488, 133, 43	2746, 219, 30
	3	3292, 266, 7	2540, 142, 30
	4	2167, 154, 41	2993, 211, 27
	5	2591, 232, 32	3626, 142, 23
	6	2981, 191, 29	3574, 61, 7
	7	2363, 169, 37	3146, 213, 7
	8	2113, 168, 43	4030, 146, 6
	Average	2406, 61, 288	2840 62, 160
17/24.6.87	1	3352, 178, 14	3584, 137, 19
	2	2993, 184, 27	2766, 235, 20
	3	2056, 165, 42	2650, 213, 23
	4	1856, 155, 56	3271, 115, 27
	5	2739, 157, 43	3461, 126, 16
	6	2797, 170, 33	3433, 119, 9
	7	2681, 165, 32	3486, 220, 9
	8	2462, 216, 31	3240, 127, 10
	Average	2482, 60, 278	3178, 56, 133
18/25.6.87	1	1720, 145, 59	3353, 210, 17
	2	1500, 107, 62	3512, 126, 13
	3	1896, 106, 62	3897, 138, 18
	4	2110, 111, 53	3134, 200, 21
	5	1829, 163, 57	3715, 153, 12
	6	1738, 158, 50	3990, 177, 8
	7	2580, 88, 54	3667, 164, 9
	8	2456, 174, 36	2747, 349, 18
	Average	1946, 46, 433	3427, 67, 116

* Champion Park and Denmark Hill were surveyed on consecutive weeks.
** Consecutive 15 minute periods from 0730 hours.
*** Figures are saturation flow, standard error and sample size respectively.

TABLE F14 : SATURATION FLOWS WITHOUT EXIT BLOCKING

LOCATION	MEASURED/ PREDICTED *	SATURATION FLOW *		DIFFERENCE (%)
		WITHOUT BUS LANE	WITH BUS LANE	
Denmark Hill	Measured	3065	2874	-6.2
	Predicted	3539	2737∇	-22.3
Champion Park	Measured	3512	3541	+0.8
	Predicted	3660	3040∇	-16.9

* Notes 1. Figures for fully saturated cycles only.

2. The measured 'without' bus lane saturation flows are taken from the with bus lane data excluding intervals at the end of each phase which may have been affected by the bus lane: Insufficient unblocked cycles for the without bus lane case were observed (see section 11.2.1).
3. Saturation flow predictions based on RR67 relationships and procedure in Figure 7.3.

∇ Assuming full use of the setback and no bus lane violations

TABLE F15 : AVERAGE JOURNEY TIMES : DENMARK HILL — AFTER SURVEYS

SURVEY DATE	PARAMETER	VEHICLE TYPE	AVERAGE JOURNEY TIME (SECS/VEH)								
			TIME INTERVAL (15 MINS FROM 0730 HRS)								WHOLE SURVEY
			1	2	3	4	5	6	7	8	
23.6.87	Journey time	Buses	139	155	164	158	158	124	179	159	153
	Sample size		4	4	5	1	4	7	5	6	
	Standard Deviation		48	48	78	0	67	37	58	31	
	Journey time	Non-priority	131	131	69	88	100	72	91	115	100
	Sample size		18	18	20	18	19	16	18	17	
	Standard Deviation		64	91	19	27	39	20	31	47	
24.6.87	Journey time	Buses	117	138	192	173	189	123	130	171	148
	Sample size		4	6	4	4	3	7	6	3	
	Standard Deviation		30	33	44	69	47	27	30	26	
	Journey time	Non-priority	63	78	142	171	104	77	72	79	98
	Sample size		17	22	22	16	23	14	15	24	
	Standard Deviation		17	26	53	70	31	20	20	27	
25.6.87	Journey time	Buses	119	153	198	215	249	264	176	127	190.
	Sample size		3	8	1	6	5	5	5	4	
	Standard Deviation		46	33	0	52	51	43	44	69	
	Journey time	Non-priority	201	278	338	203	371	451	319	106	283
	Sample size		11	12	10	10	10	9	13	14	
	Standard Deviation		49	104	52	55	65	122	184	50	

TABLE F16 : AVERAGE JOURNEY TIMES : CHAMPION PARK

AFTER SURVEYS

SURVEY DATE	PARAMETER	VEHICLE TYPE	AVERAGE JOURNEY TIME (SECS/VEH)								
			TIME INTERVAL (15 MINS FROM 0730 HRS)								WHOLE SURVEY
			1	2	3	4	5	6	7	8	
16.6.87	Journey time	Buses	247	223	230	190	167	-	175	149	199
	Sample size		6	4	4	4	4	0	6	4	
	Standard Deviation		62	50	16	36	17	0	37	36	
	Journey time	Non-priority	250	170	172	181	104	98	147	98	154
	Sample size		11	8	13	14	9	12	8	10	
	Standard Deviation		47	54	58	41	30	30	32	26	
17.6.87	Journey time	Buses	142	229	199	204	190	198	190	140	181
	Sample size		5	4	5	2	6	3	2	6	
	Standard Deviation		27	19	26	18	49	4	88	20	
	Journey time	Non-priority	101	125	123	136	101	100	92	112	113
	Sample size		19	16	14	17	10	12	12	12	
	Standard Deviation		23	35	32	33	33	24	22	30	
18.6.87	Journey time	Buses	165	139	163	167	159	155	176	145	158
	Sample size		4	3	5	5	4	3	4	7	
	Standard Deviation		49	15	35	60	25	13	15	37	
	Journey time	Non-priority	95	103	93	103	108	97	94	125	101
	Sample size		16	23	17	20	13	17	20	11	
	Standard Deviation		18	34	20	33	26	30	24	32	

TABLE F17 : TRAFFIC RE-ASSIGNMENT ONTO FERNDENE ROAD - OBSERVED AND PREDICTED

ITEM	SURVEY	PARAMETER	TIME INTERVAL							
			1	2	3	4	5	6	7	8
1	24.6.87	Flow out of Ferndene Road, Link 402* (vehs/hr)	12	8	24	20	32	52	32	24
2	25.6.87	Queue length on Link 401* (vehs)	0	0	15	5	20	37	10	5
3	25.6.87	Flow out of Ferndene Road, Link 402* (vehs/hr)	8	12	32	28	52	120	64	56
4	4/5.2.86	Queue length on Link 401* (vehs): CONTRAM prediction for 'with bus lane'	0	0	0	0	8	30	50	58
5	4/5.2.86	Flow out of Ferndene Road, Link 402* (vehs/hr): CONTRAM prediction for 'with bus lane'	24	24	28	28	32	76	116	112

* See Figure F7

FIGURE F1 : LOCATION OF BUS LANES

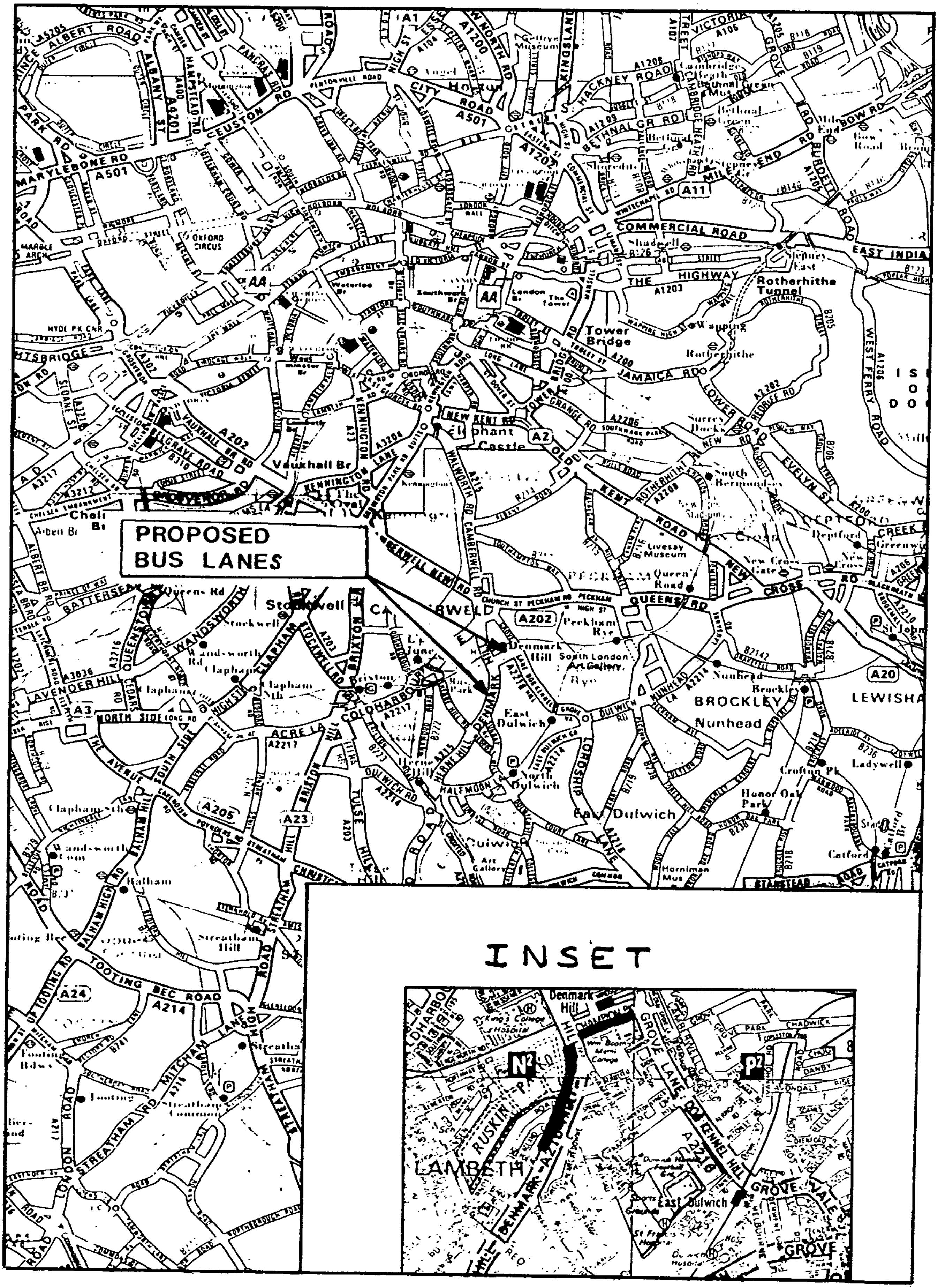


FIGURE F2 : LAYOUT OF BUS LANE LINKS

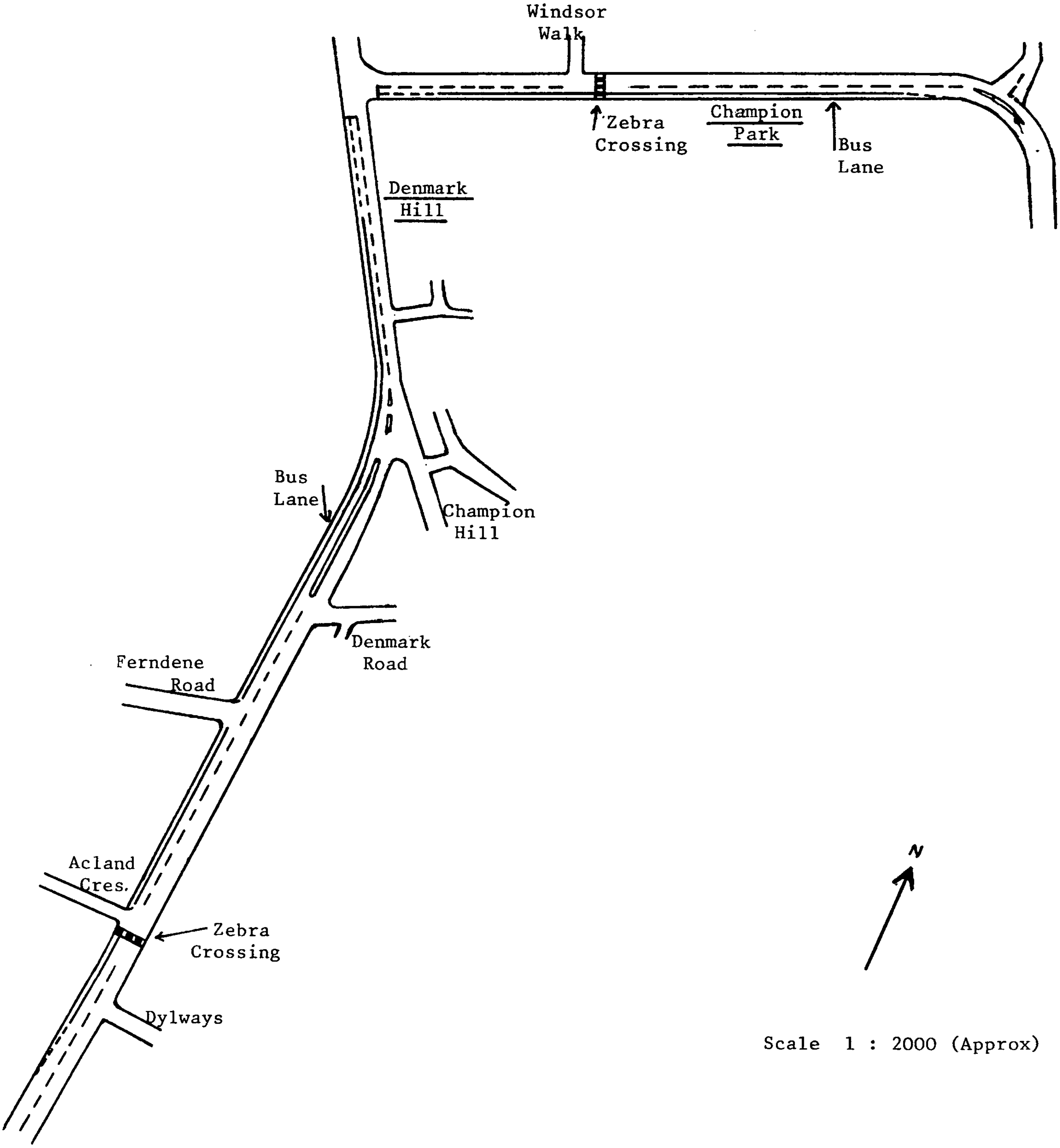
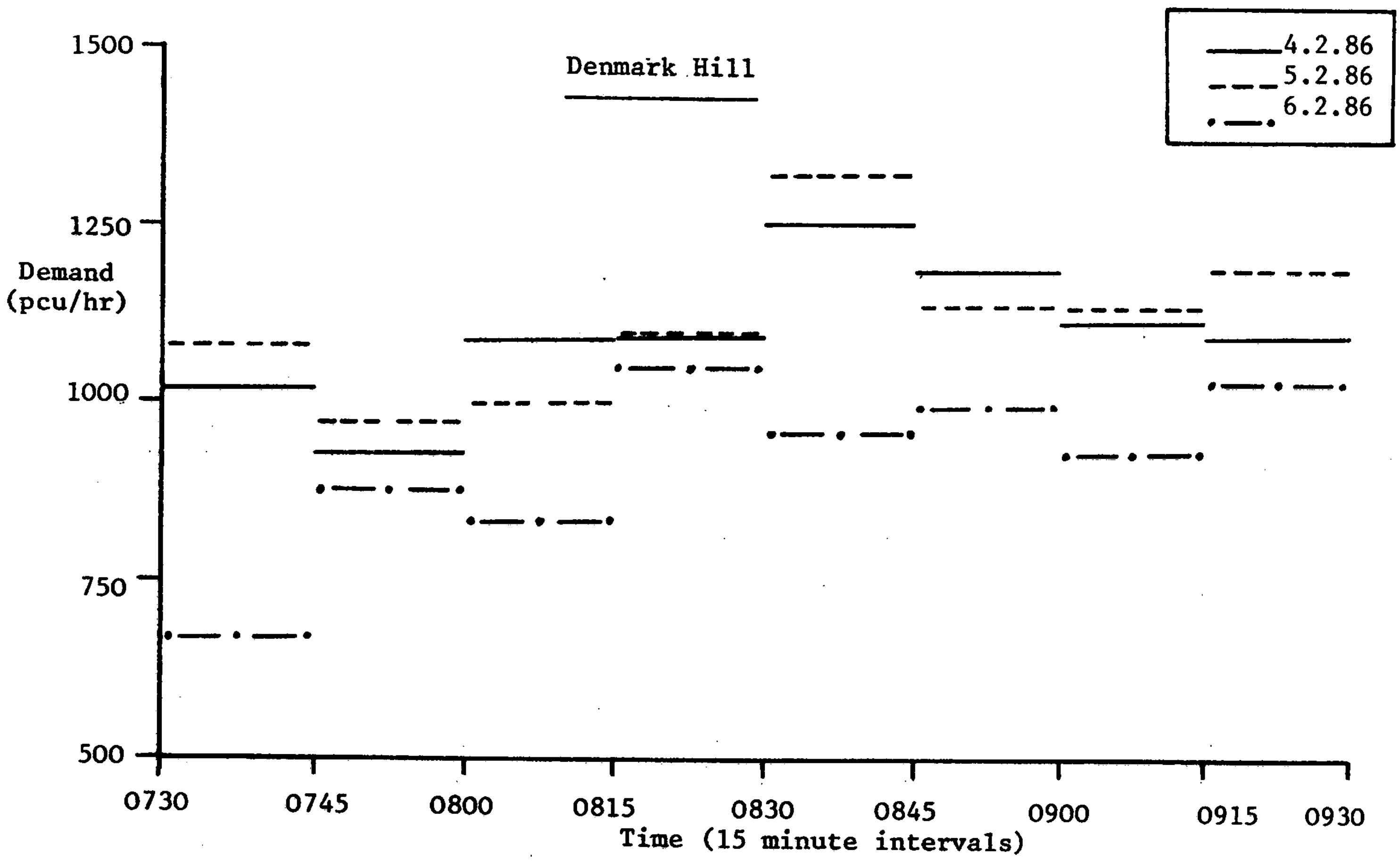
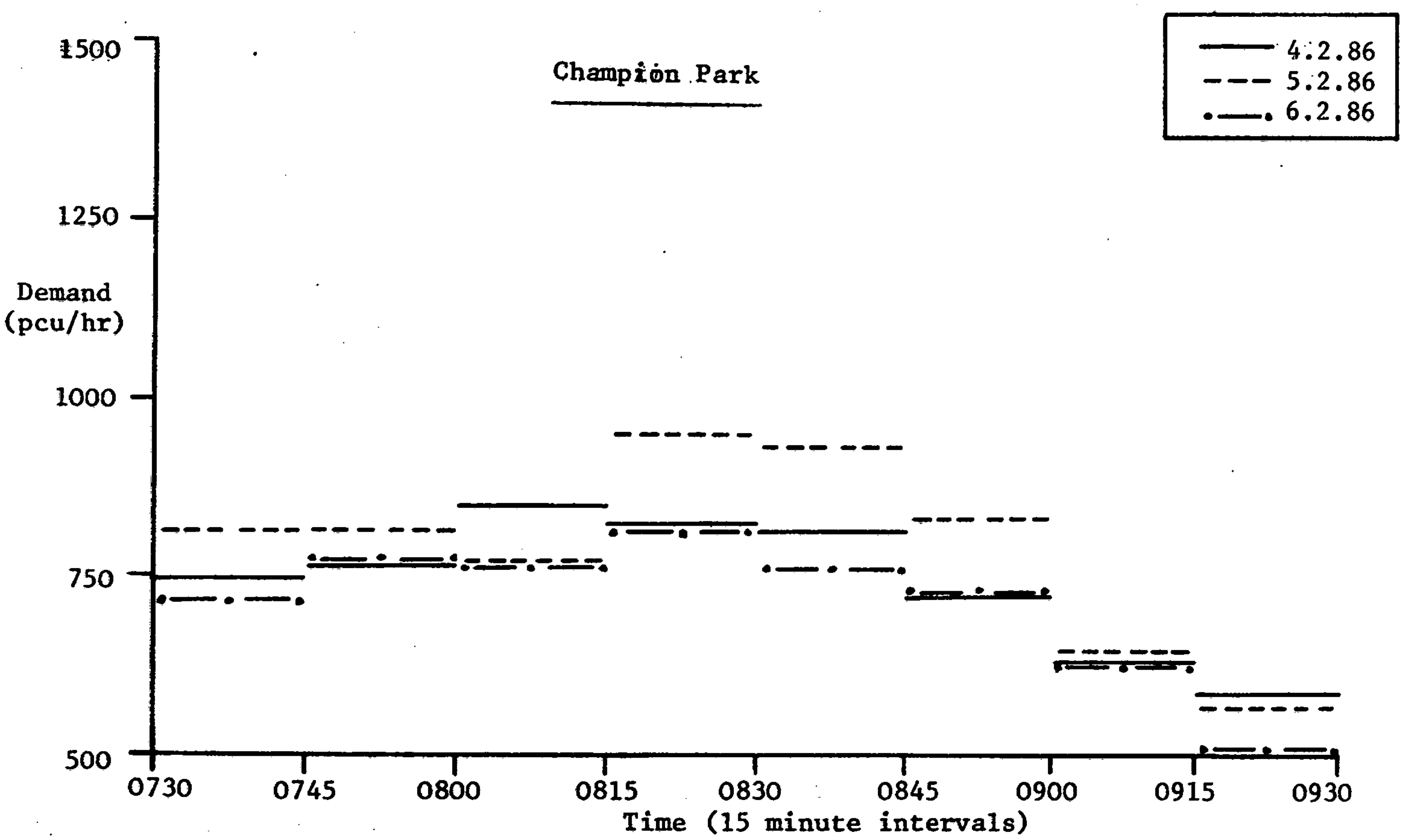


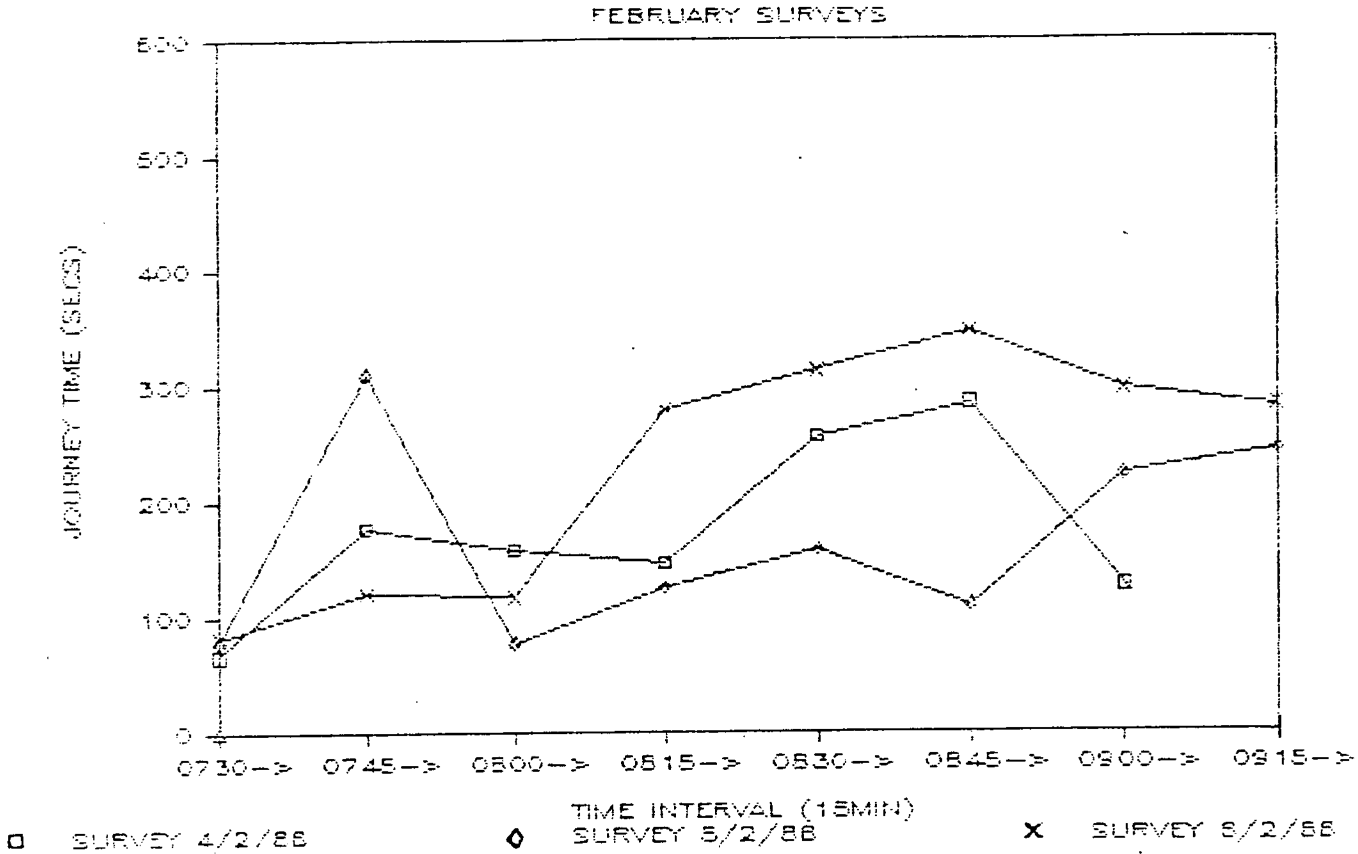
FIGURE F3 : DEMAND FLOW PROFILES

BEFORE SURVEYS





A DENMARK HILL



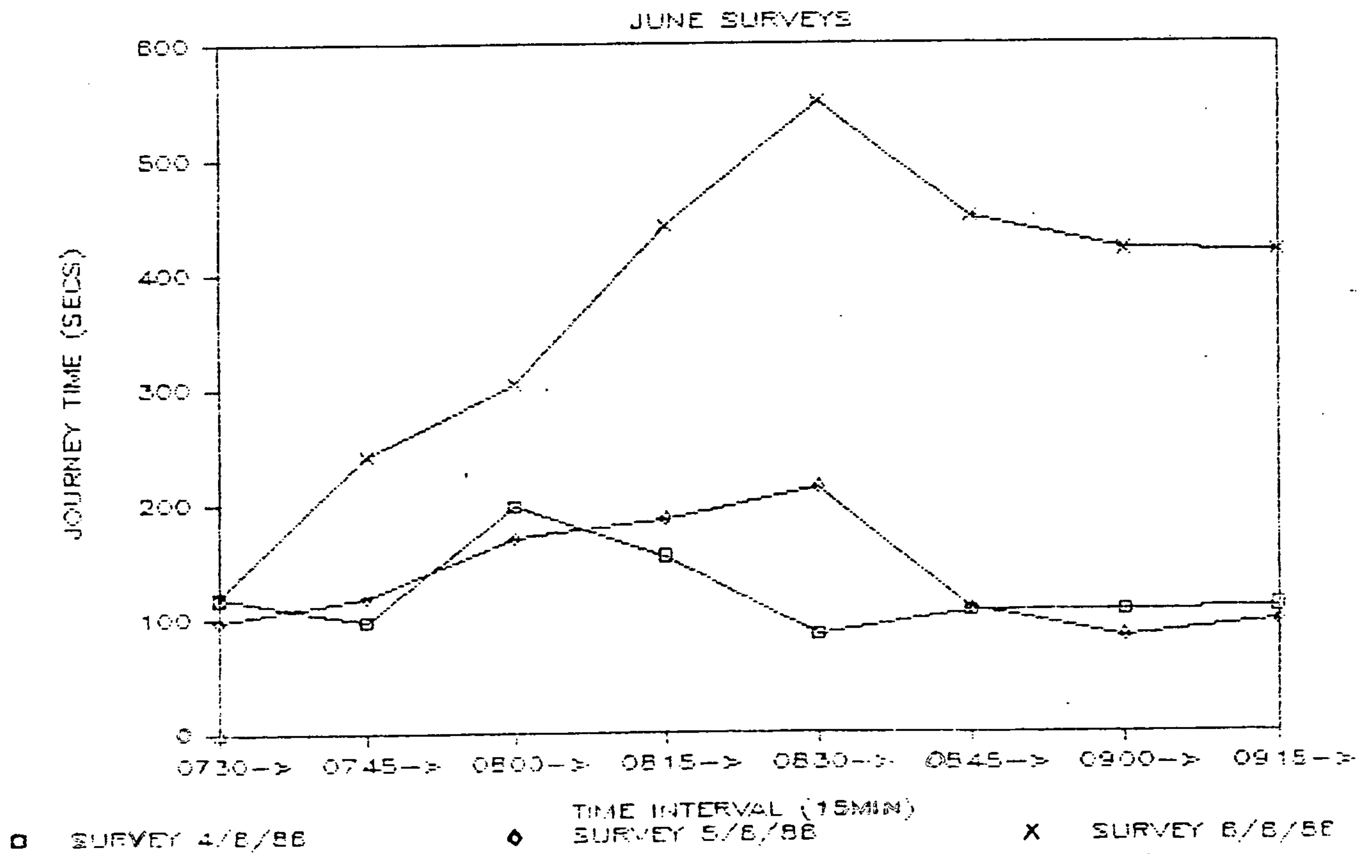
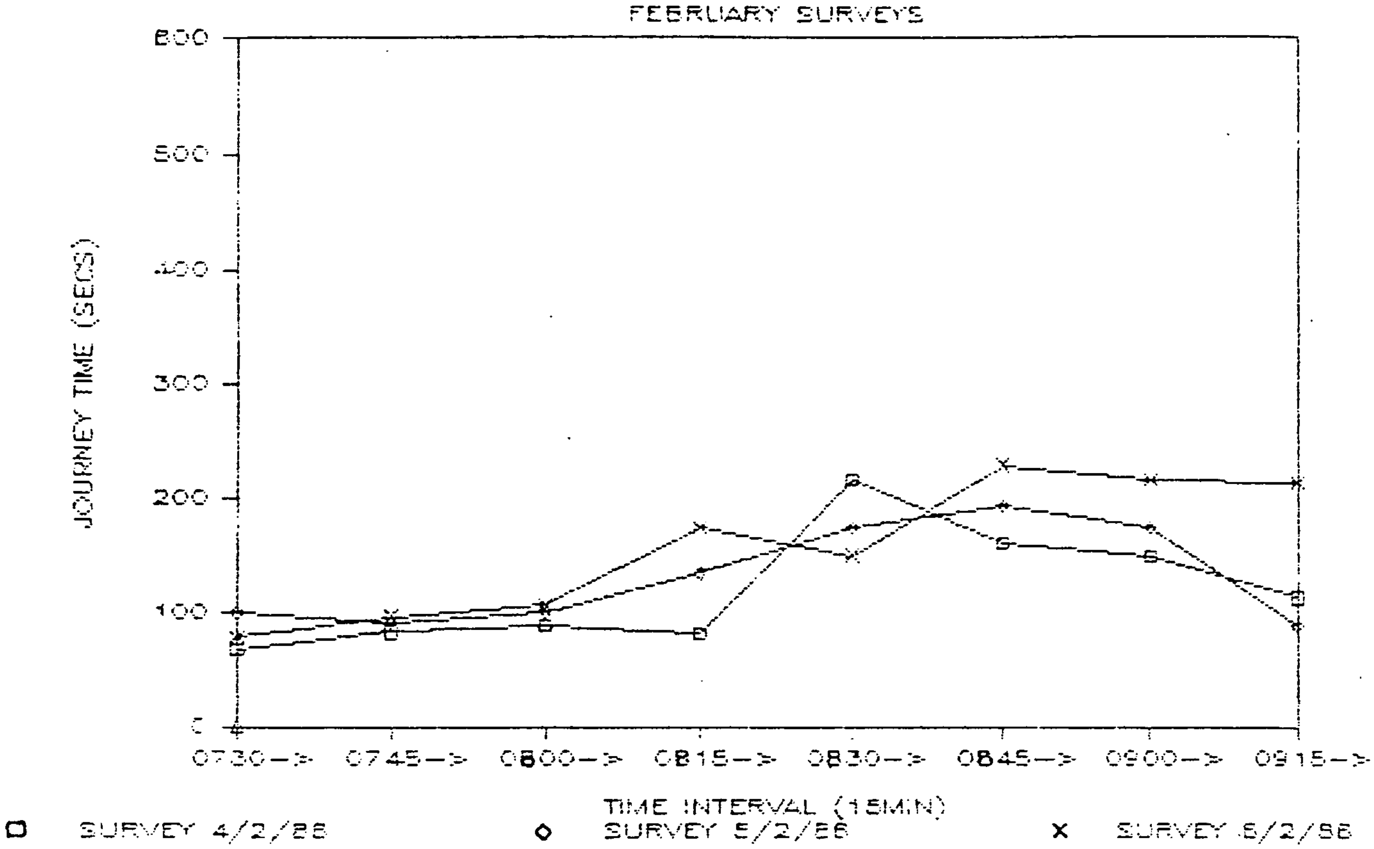


FIGURE 4 contd.

BEFORE SURVEYS

B CHAMPION PARK



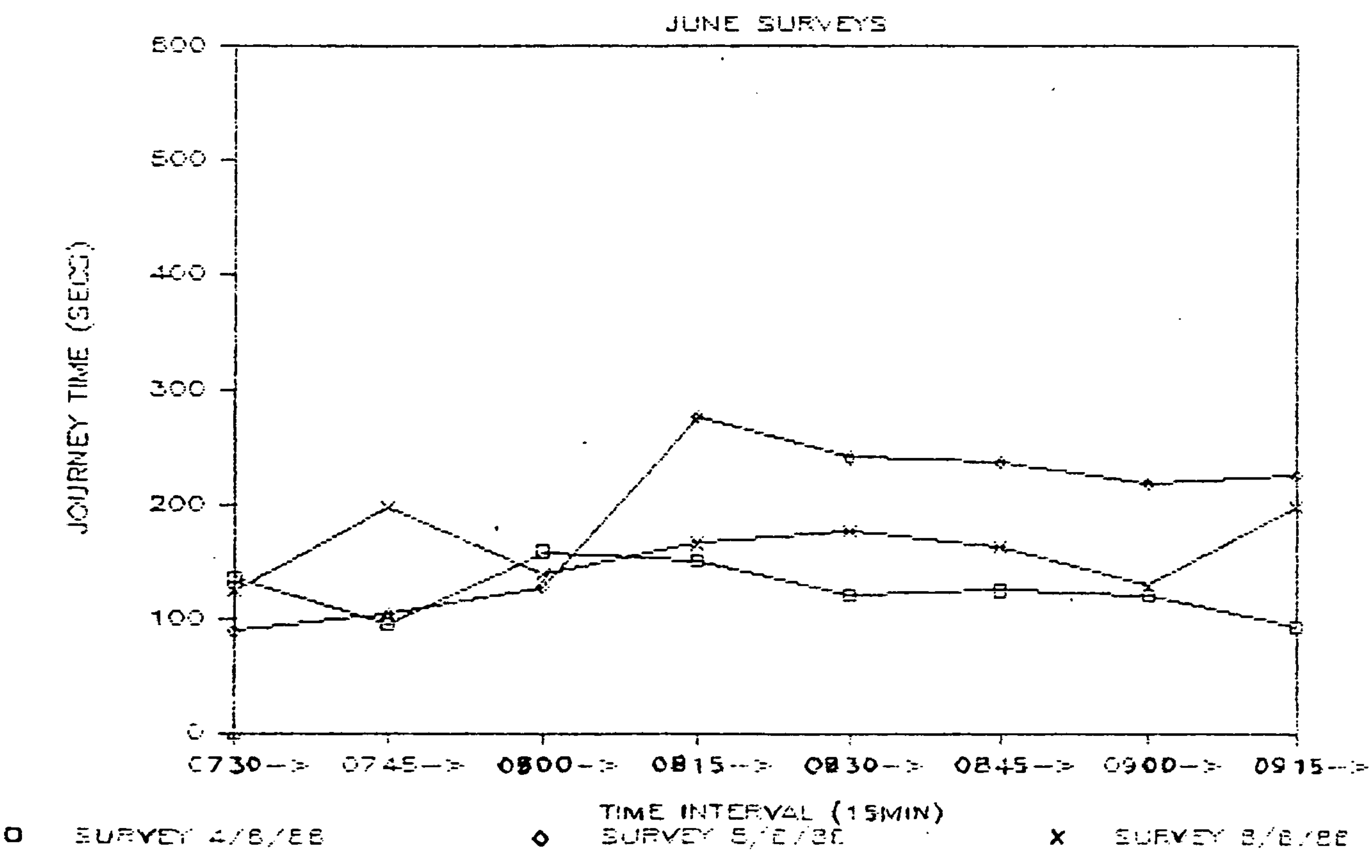
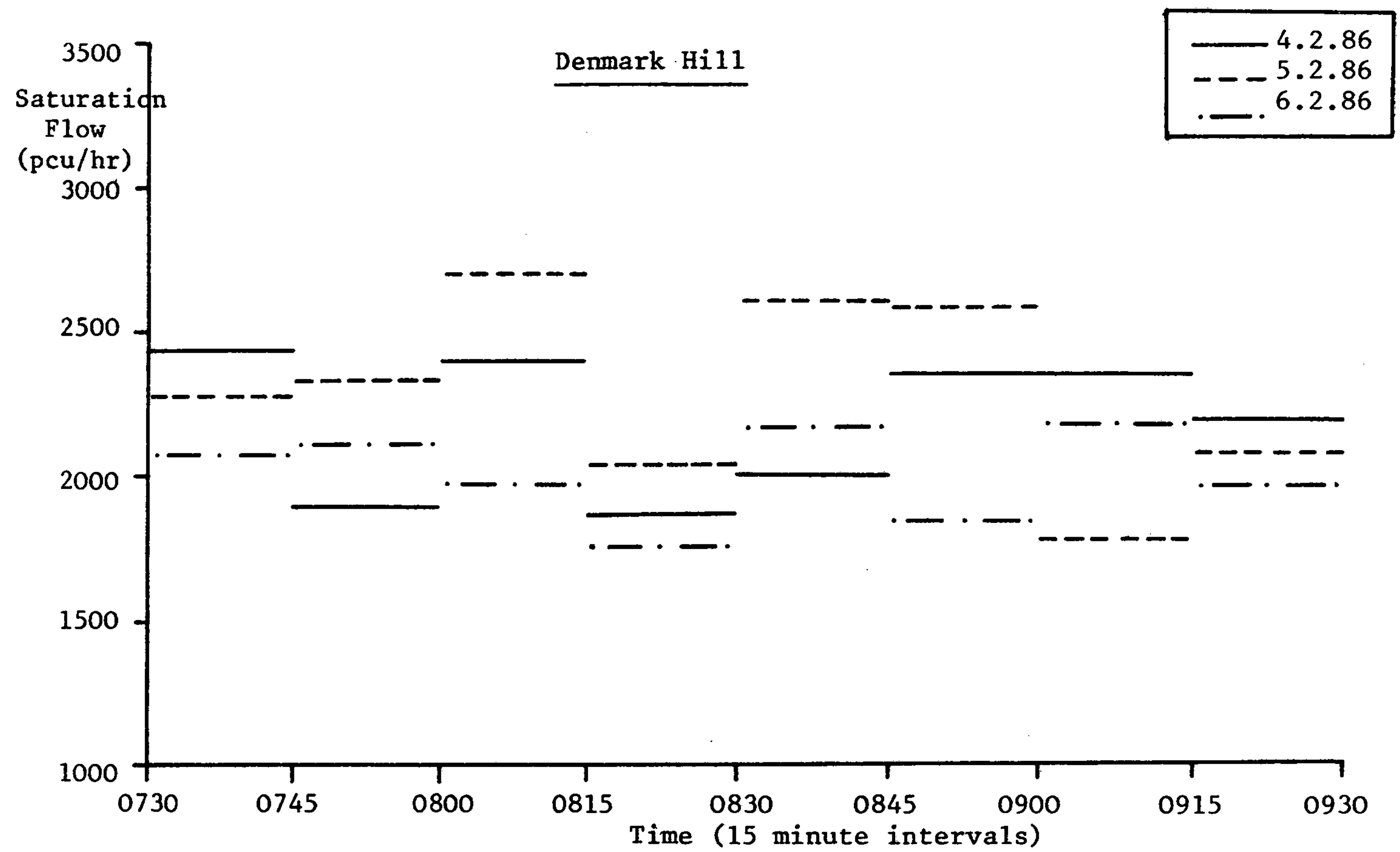


FIGURE F5 : SATURATION FLOW PROFILES

BEFORE SURVEYS



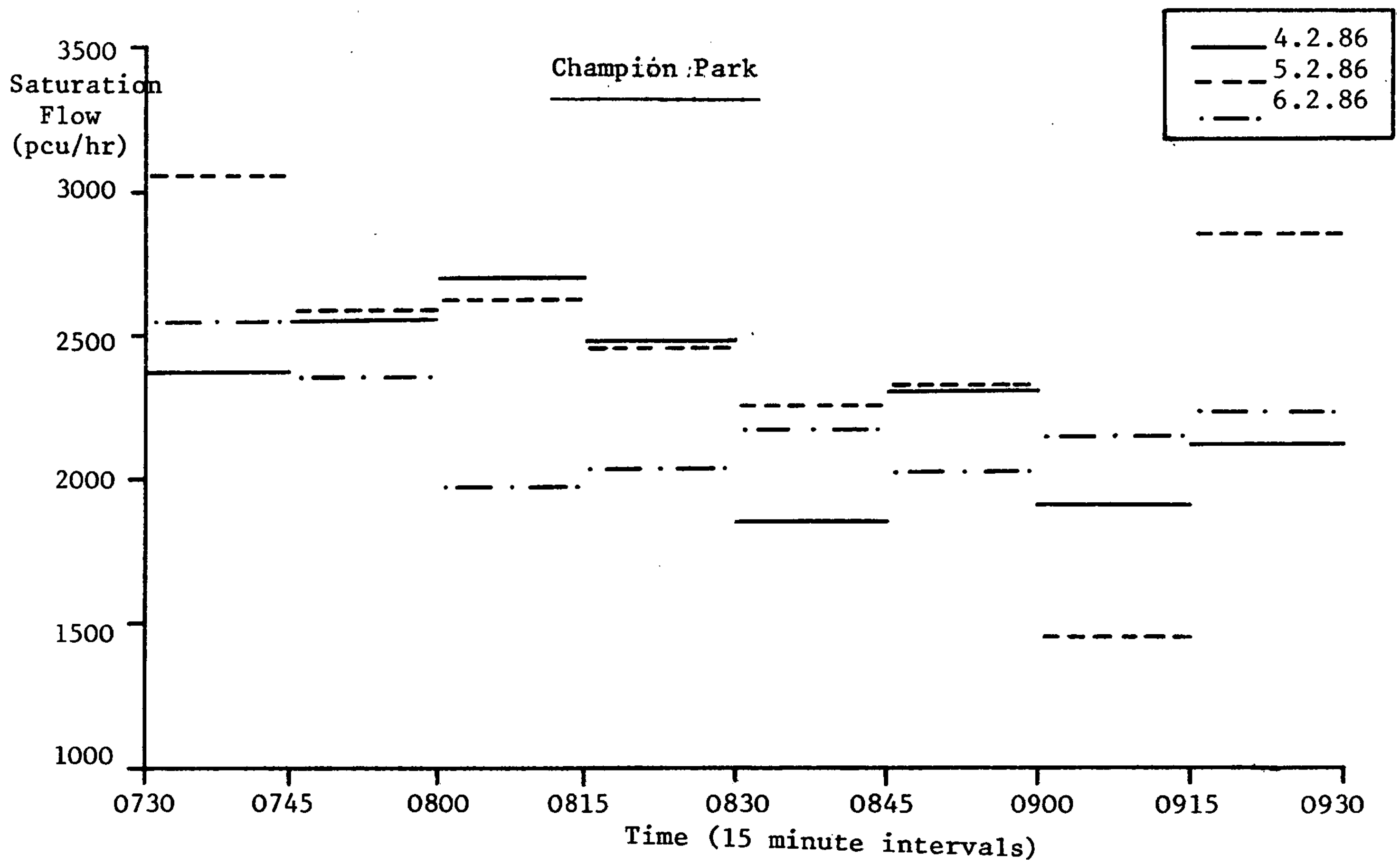


FIGURE F6 : RELATIONSHIP BETWEEN AVERAGE JOURNEY TIME AND AVERAGE QUEUE LENGTH AT DENMARK HILL

BEFORE SURVEYS

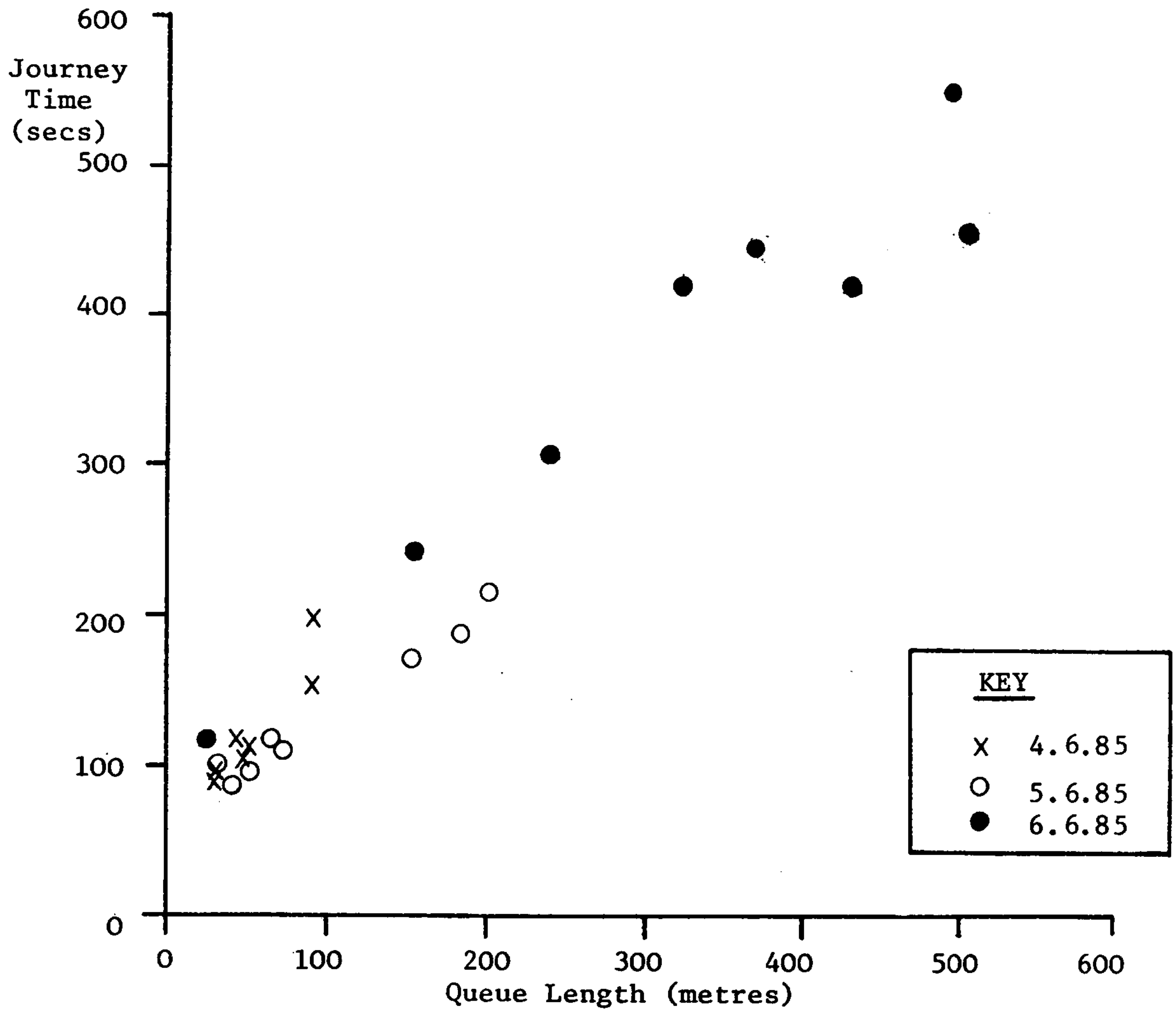
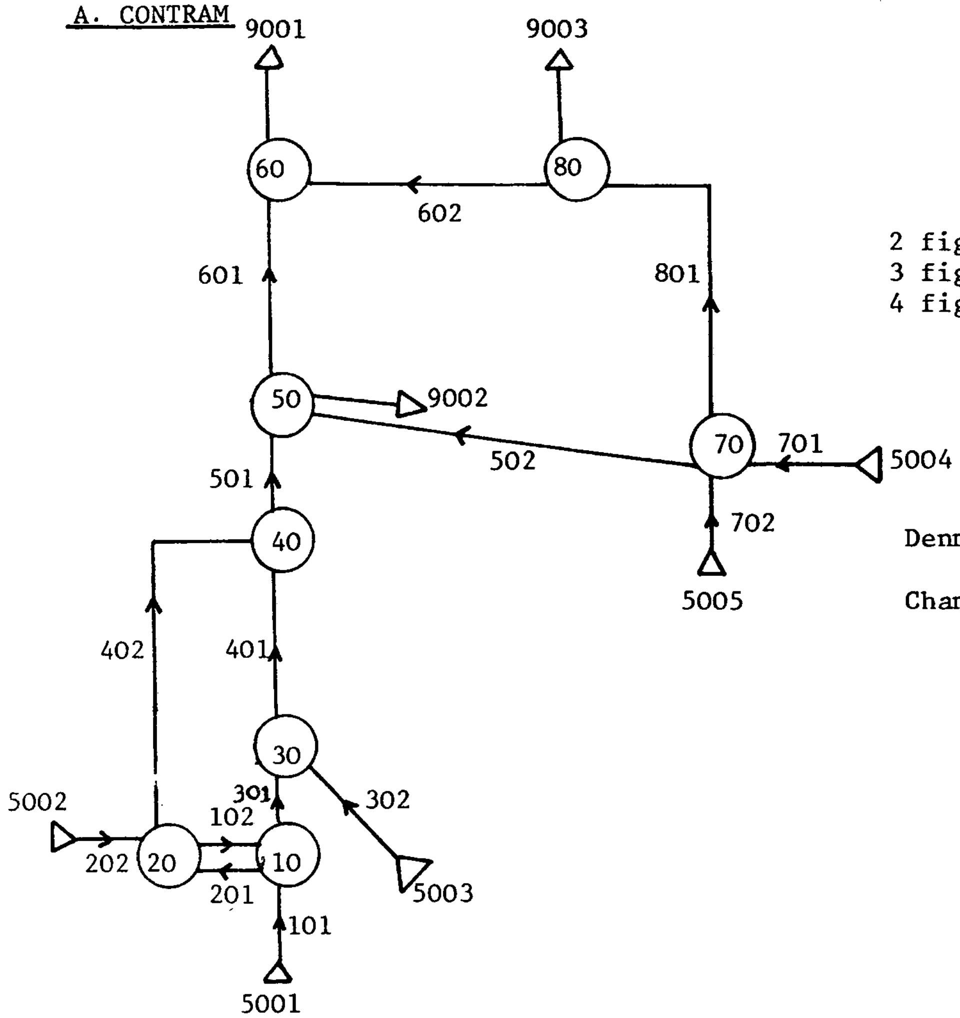


FIGURE F7 : BUS LANE NETWORK LAYOUTS

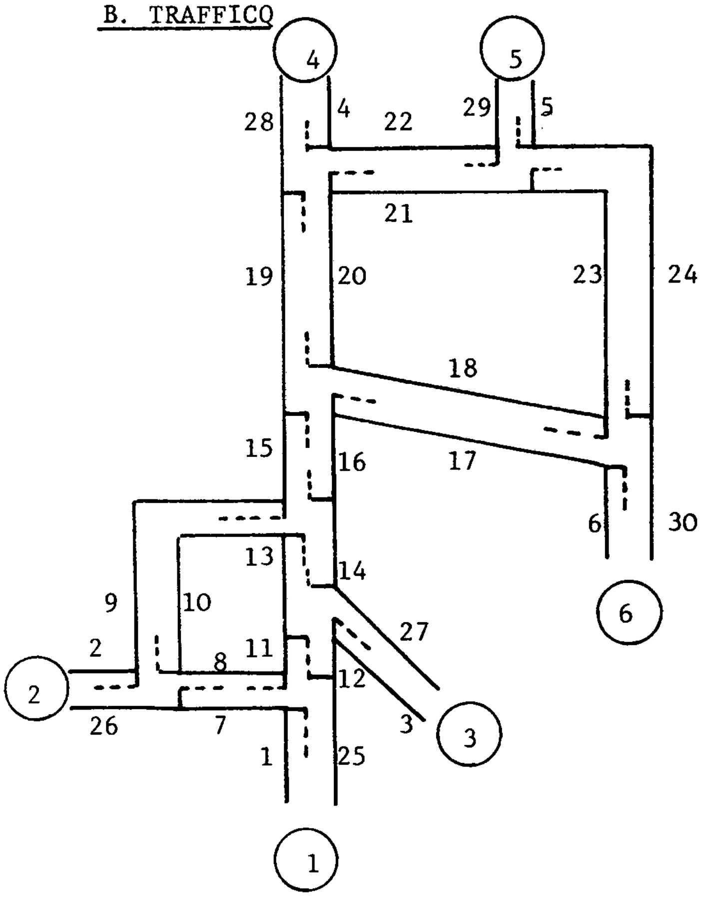
A. CONTRAM



2 figure numbers represent nodes
3 figure numbers represent links
4 figure numbers represent origin/destination

Denmark Hill bus lane is on links 401,501,601
Champion Park bus lane is on links 801, 602

B. TRAFFICQ

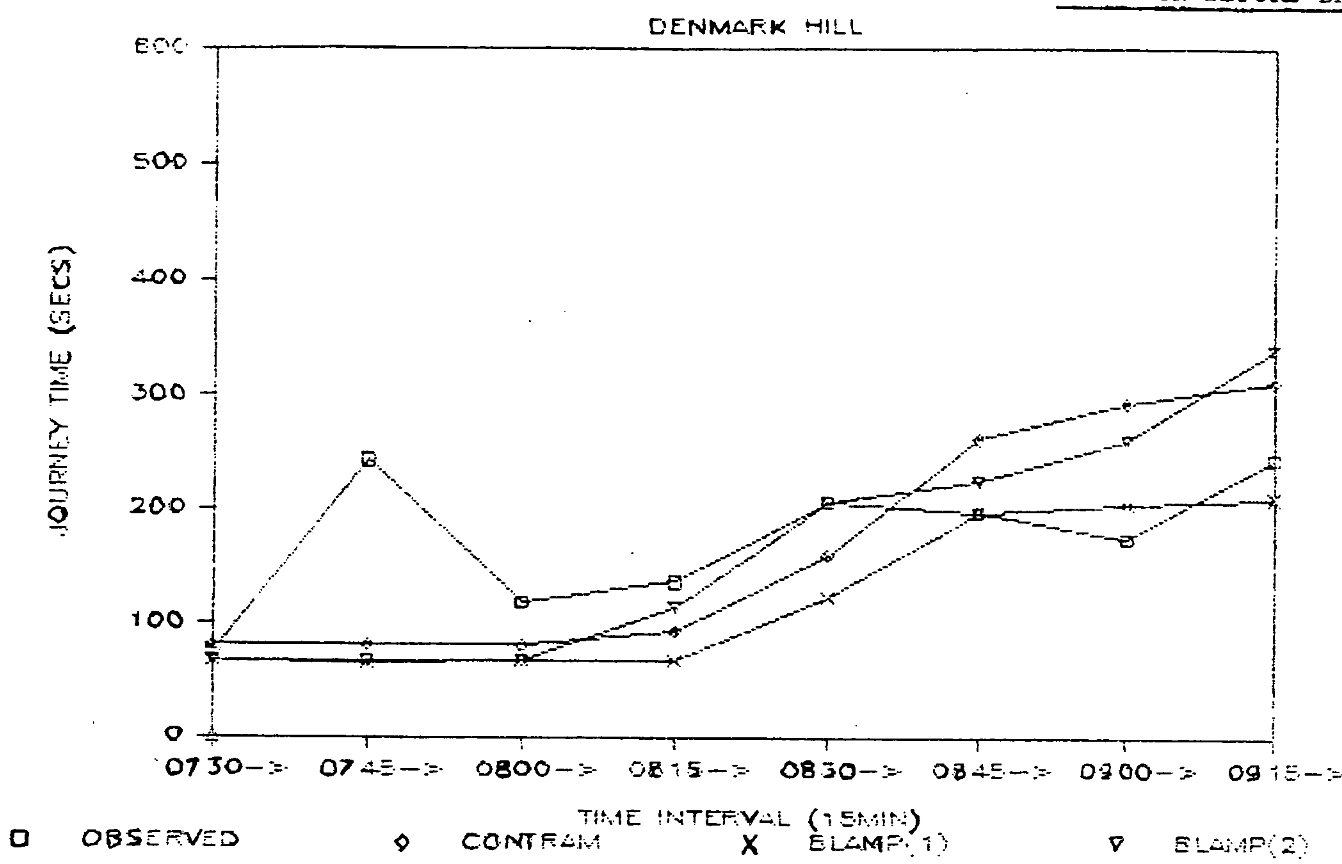


Circled numbers represent cordon points
2 figure numbers represent links

Denmark Hill bus lane is on links 13,15,19
Champion Park bus lane is on links 23,21

FIGURE F8 OBSERVED AND PREDICTED AVERAGE JOURNEY TIMES FOR NON-PRIORITY VEHICLES

BASED ON BEFORE DATA



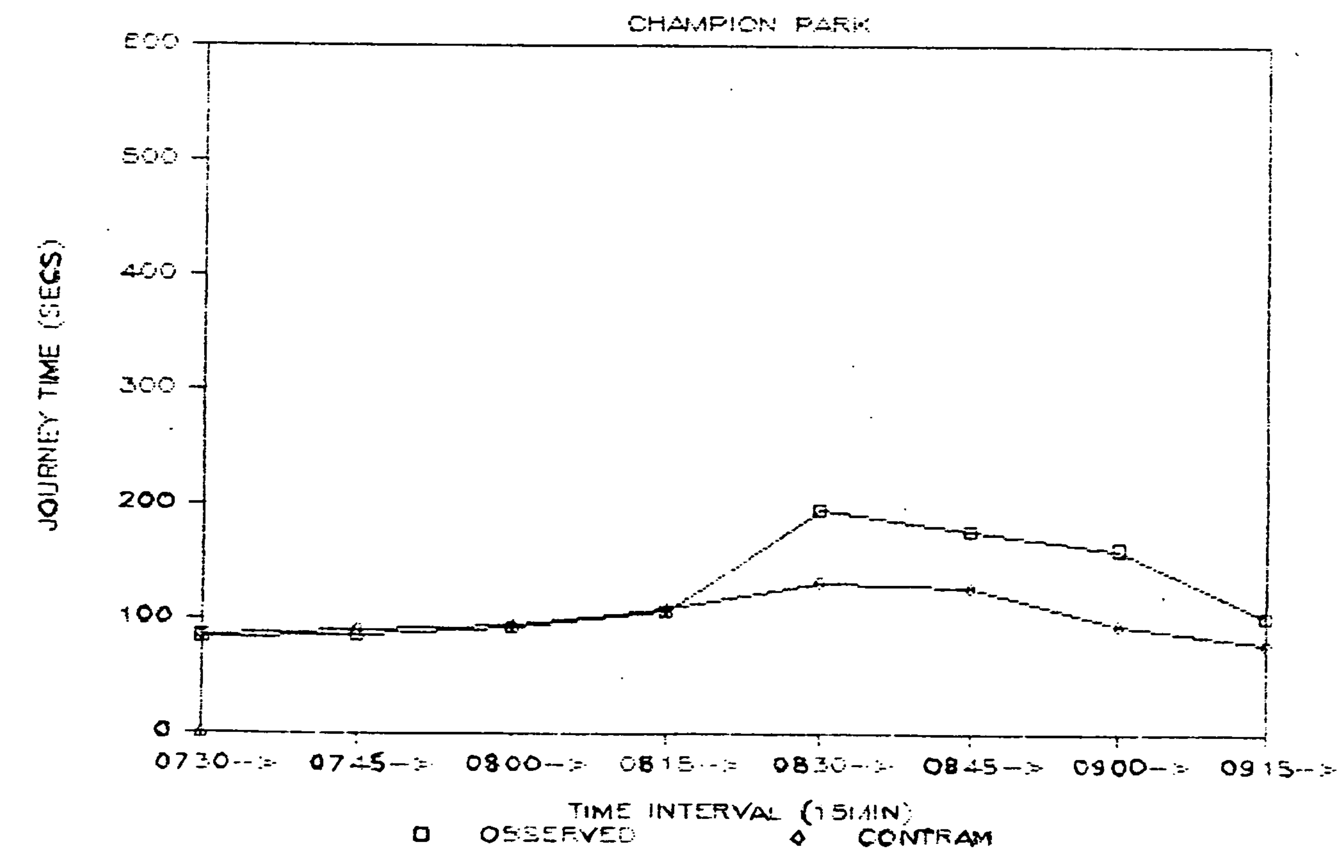
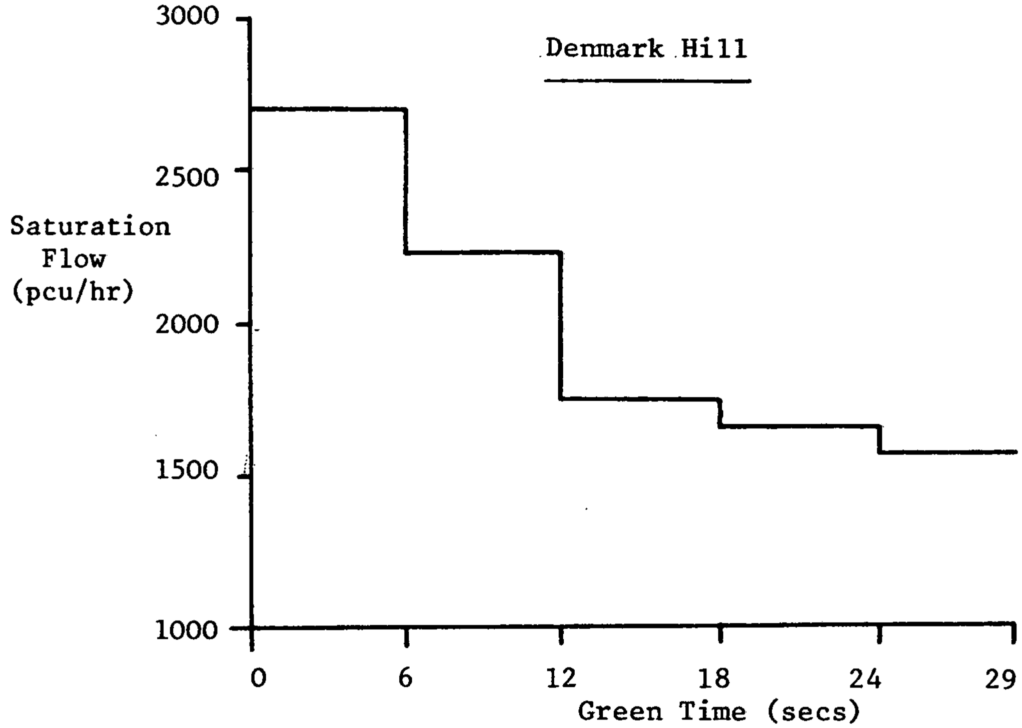


FIGURE F9 : EXAMPLES OF SATURATION FLOW PROFILES PER GREEN PHASE

BEFORE SURVEYS



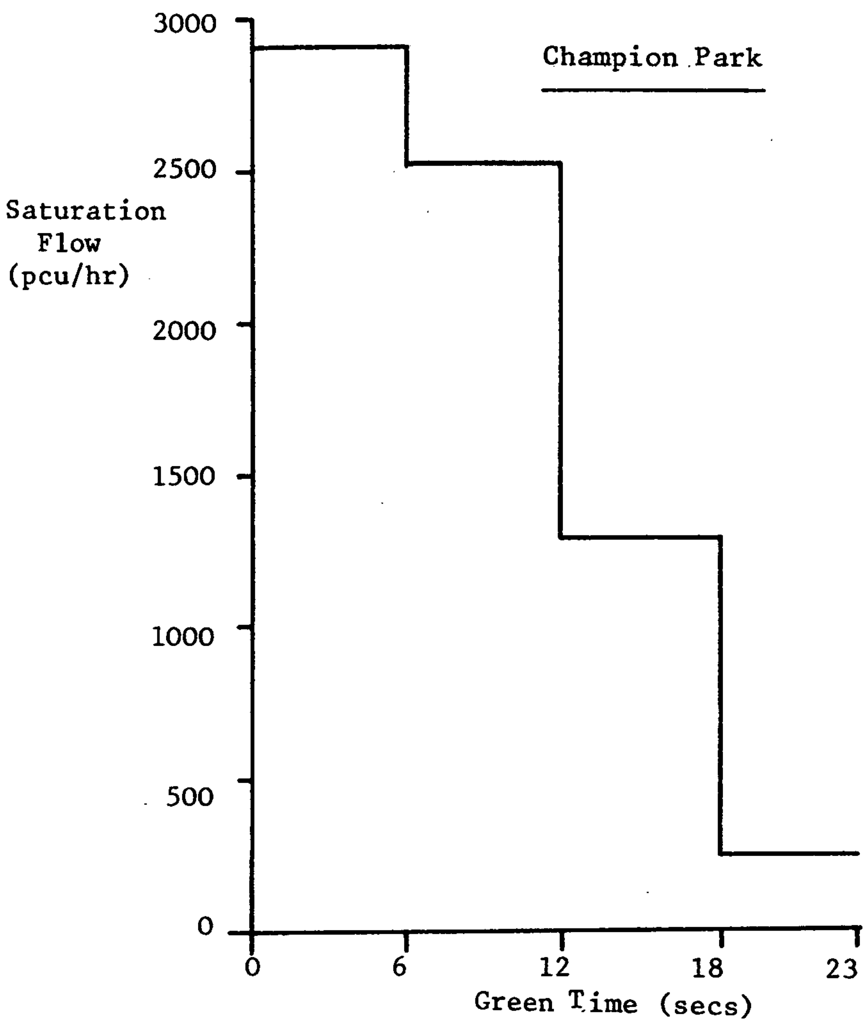
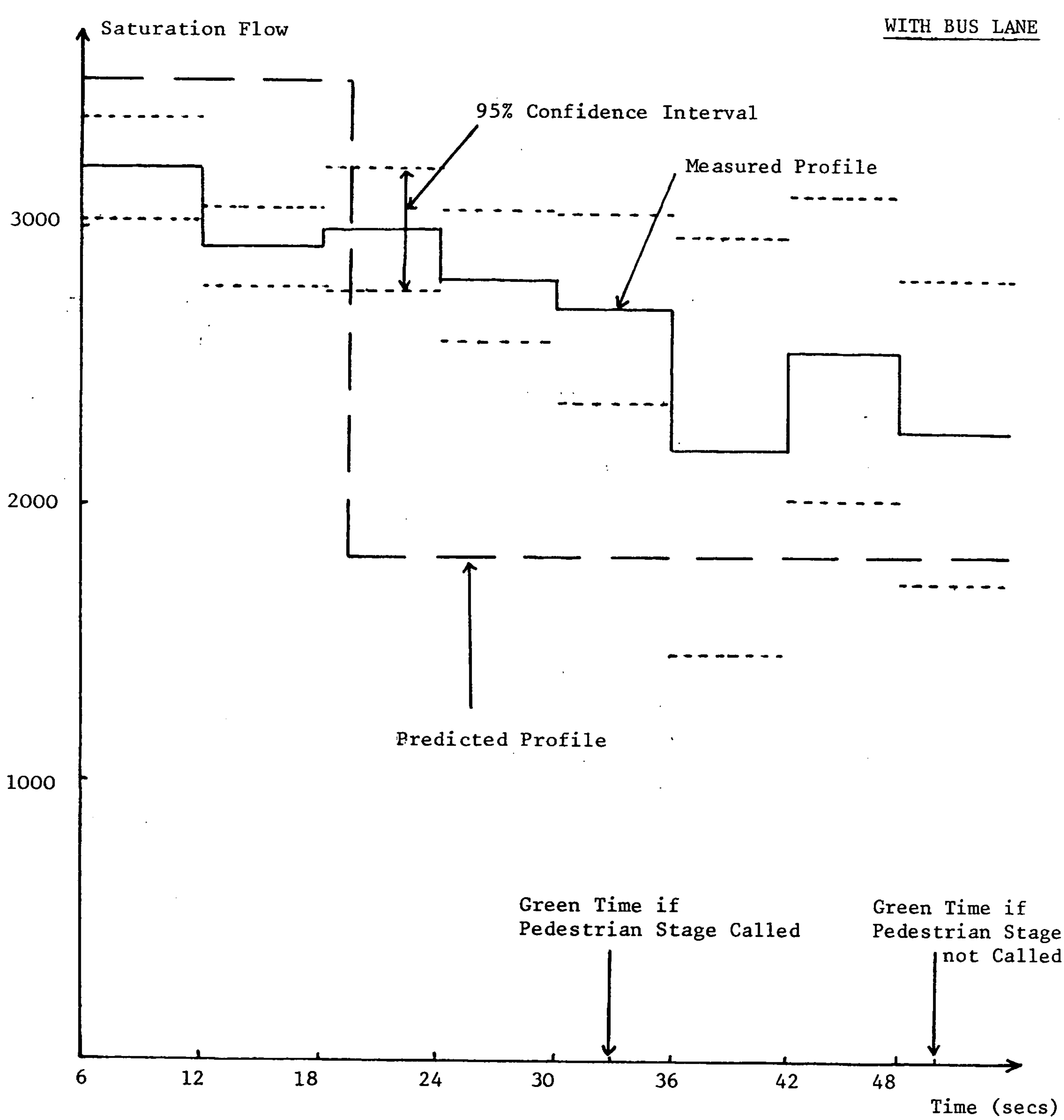
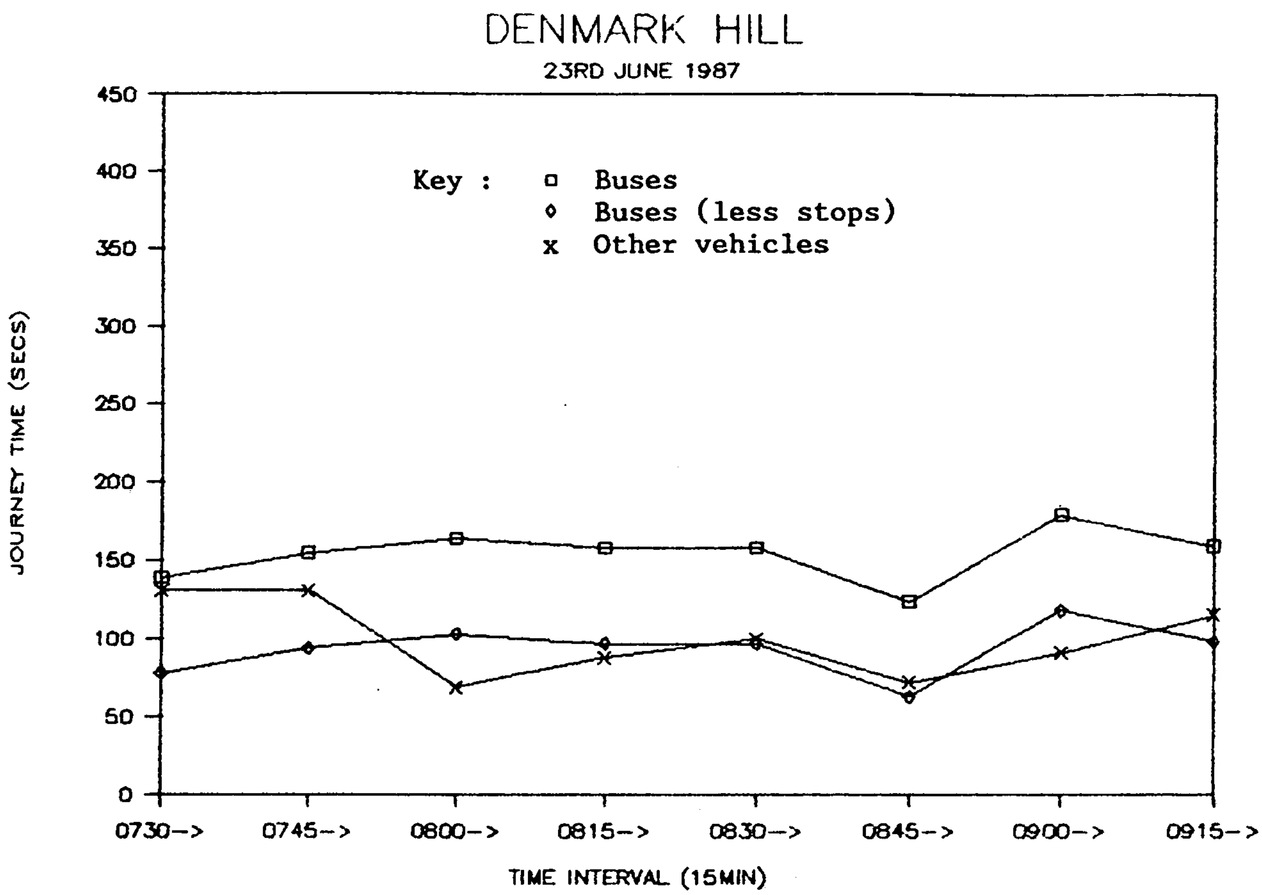


FIGURE F10 : OBSERVED AND PREDICTED CYCLIC SATURATION FLOW PROFILES : DENMARK HILL




DENMARK HILL
23RD JUNE 1987
Key : ◻ Buses
◇ Buses (less stops)
x Other vehicles
JOURNEY TIME (SECS)
450
400
350
300
250
200
150
100
50
0
0730-> 0745-> 0800-> 0815-> 0830-> 0845-> 0900-> 0915->
TIME INTERVAL (15MIN)

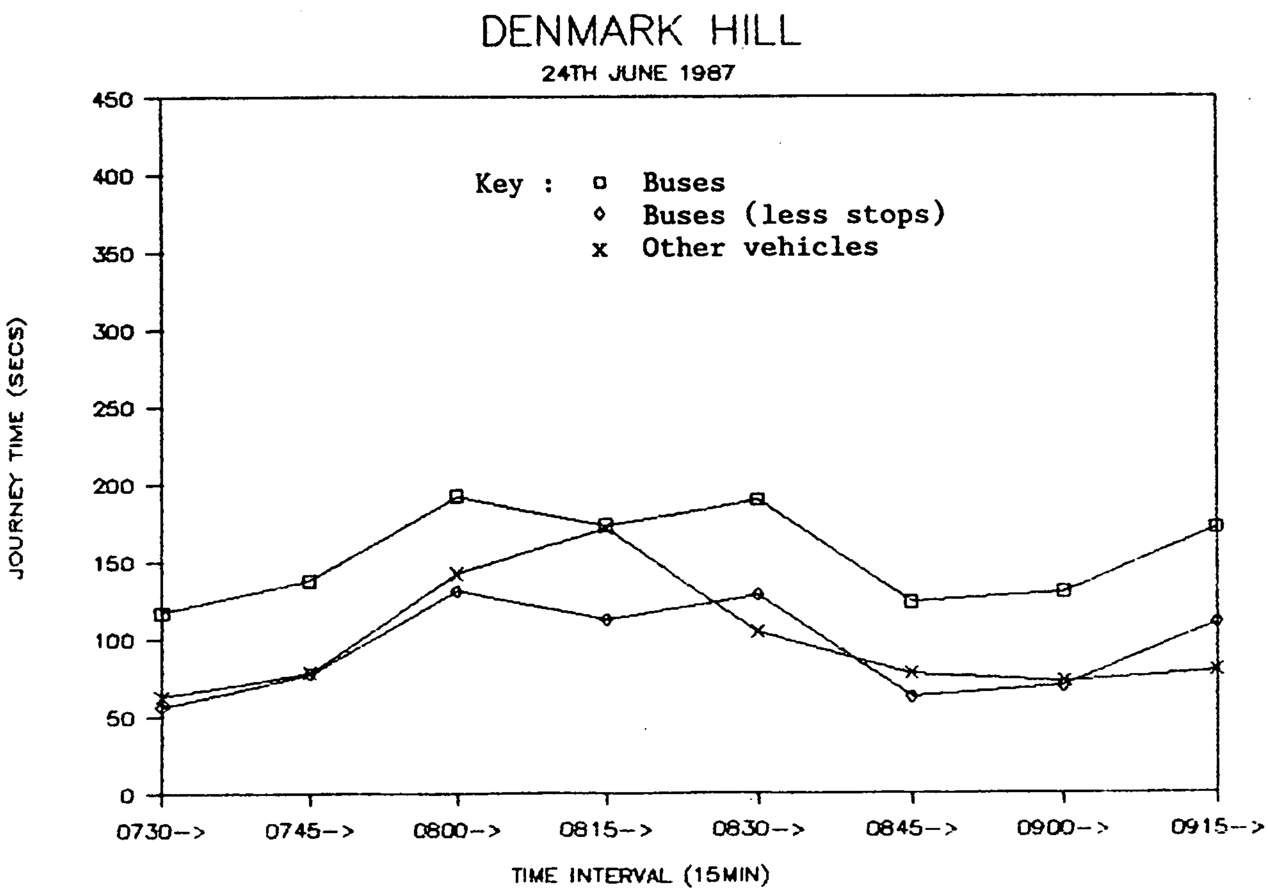
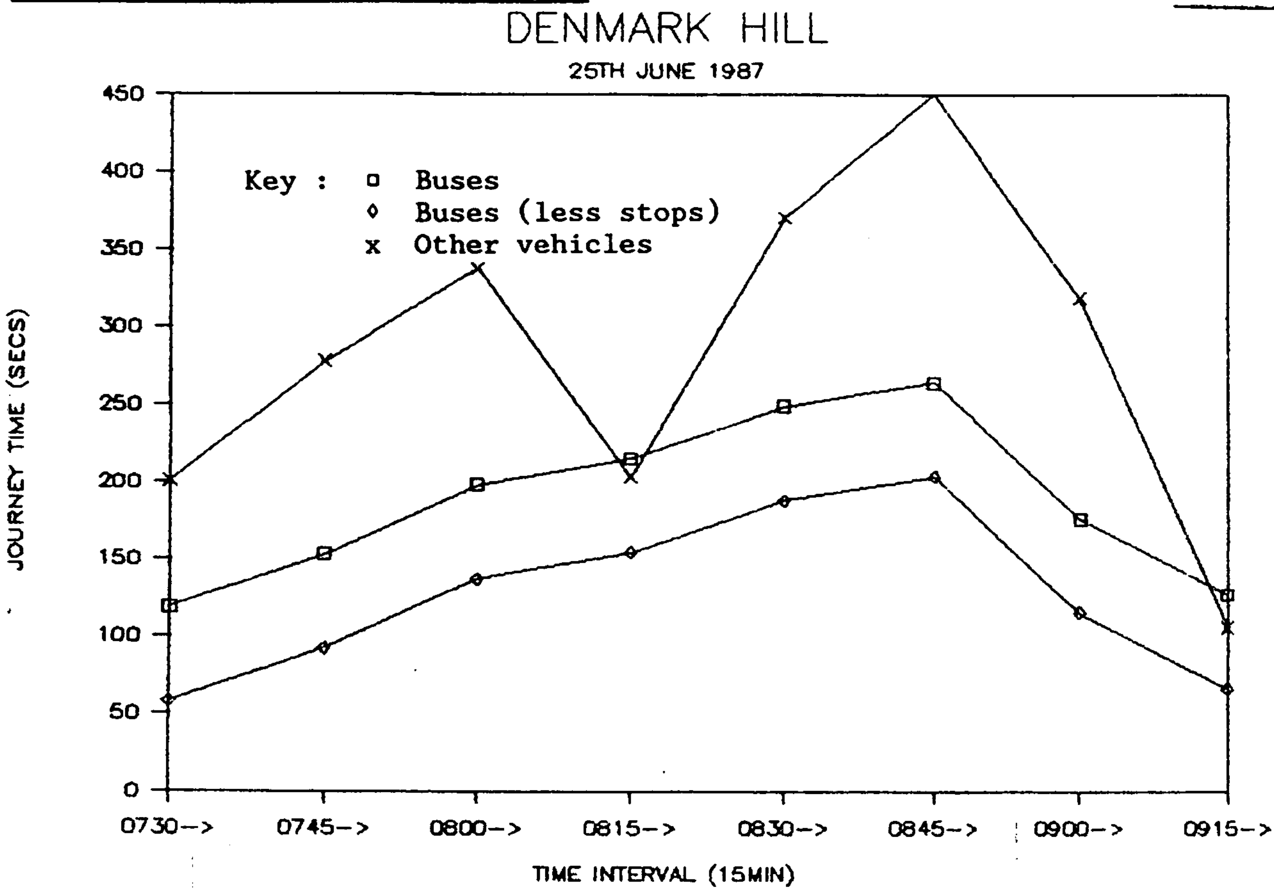

DENMARK HILL
24TH JUNE 1987
Key : ◻ Buses
◇ Buses (less stops)
x Other vehicles
JOURNEY TIME (SECS)
450
400
350
300
250
200
150
100
50
0
0730-> 0745-> 0800-> 0815-> 0830-> 0845-> 0900-> 0915->
TIME INTERVAL (15MIN)

FIGURE F12 : AVERAGE JOURNEY TIMES

AFTER SURVEYS



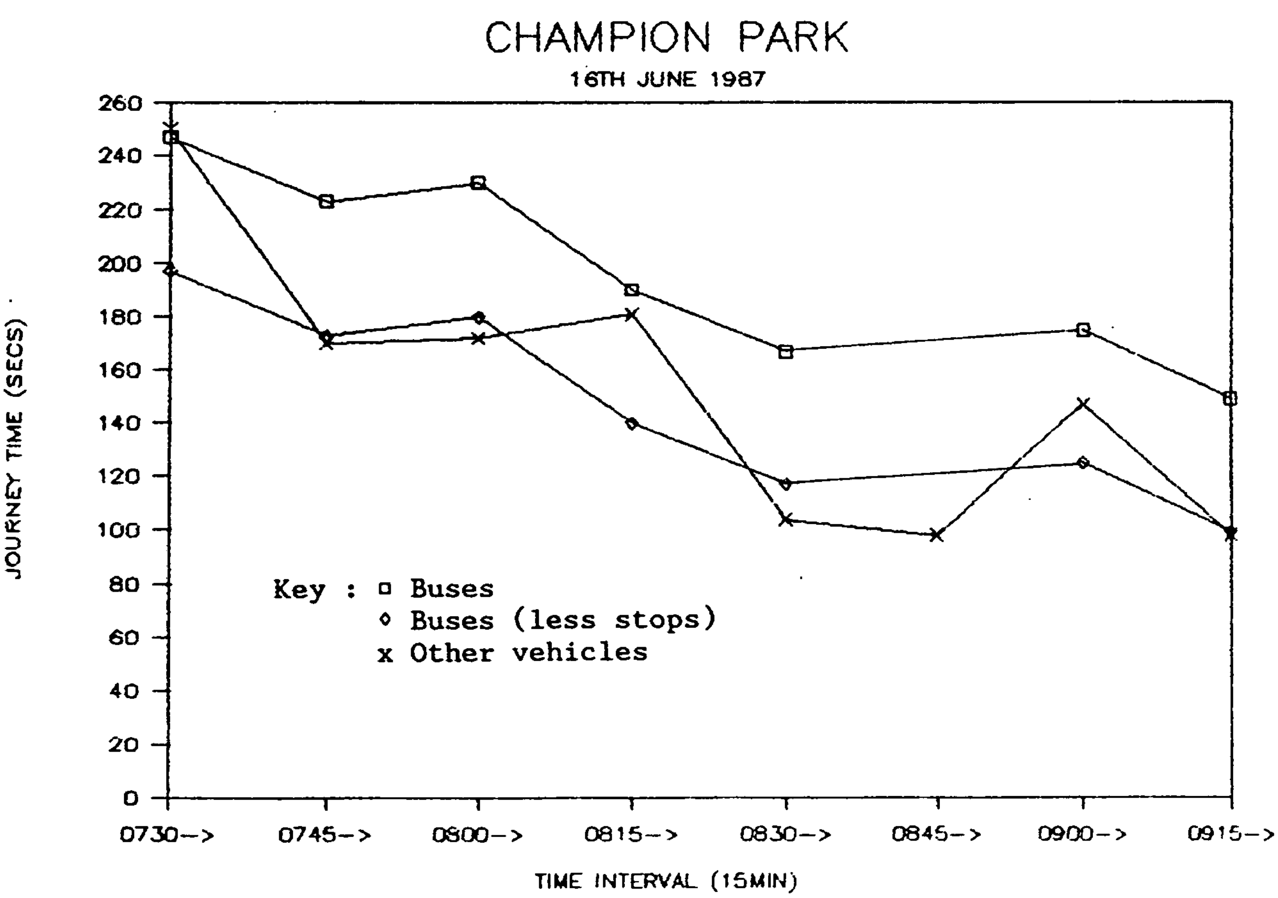
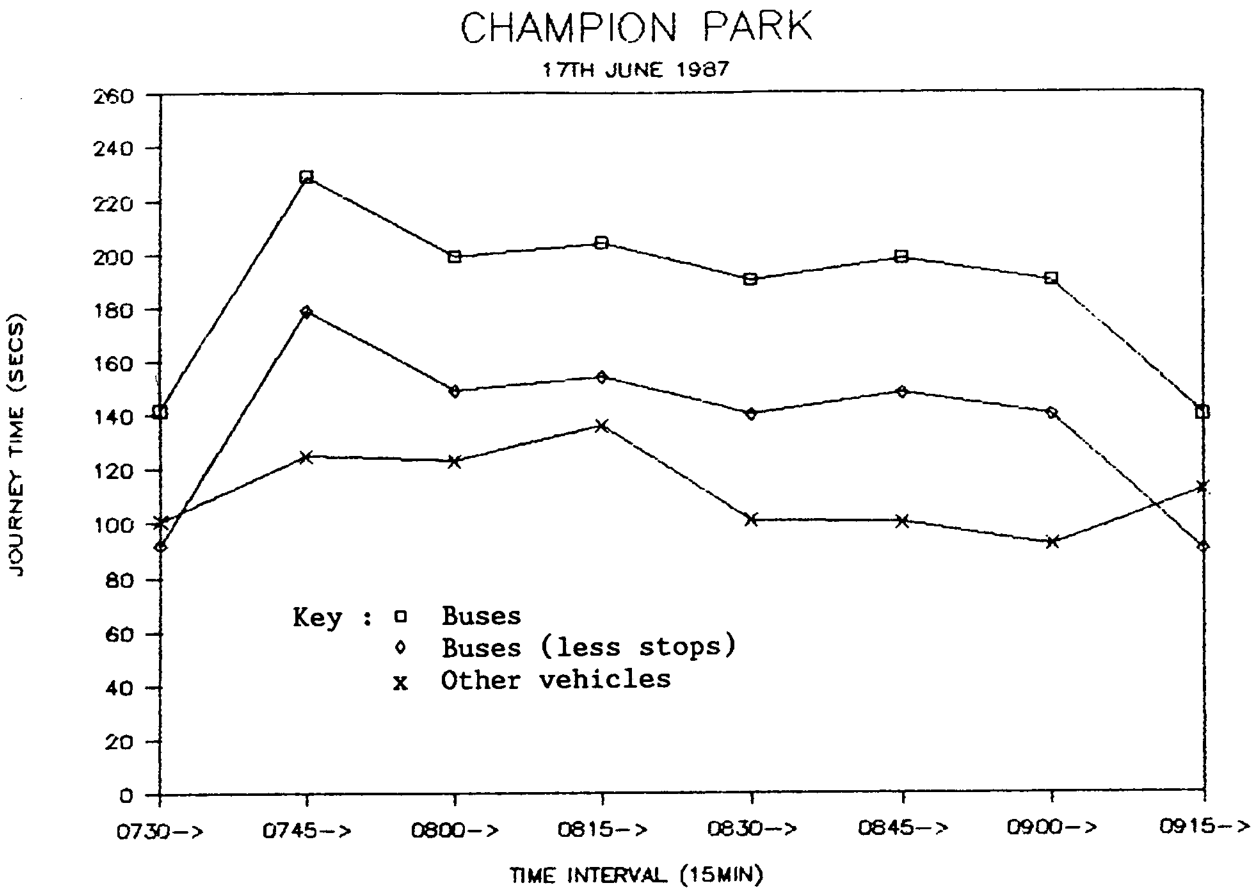
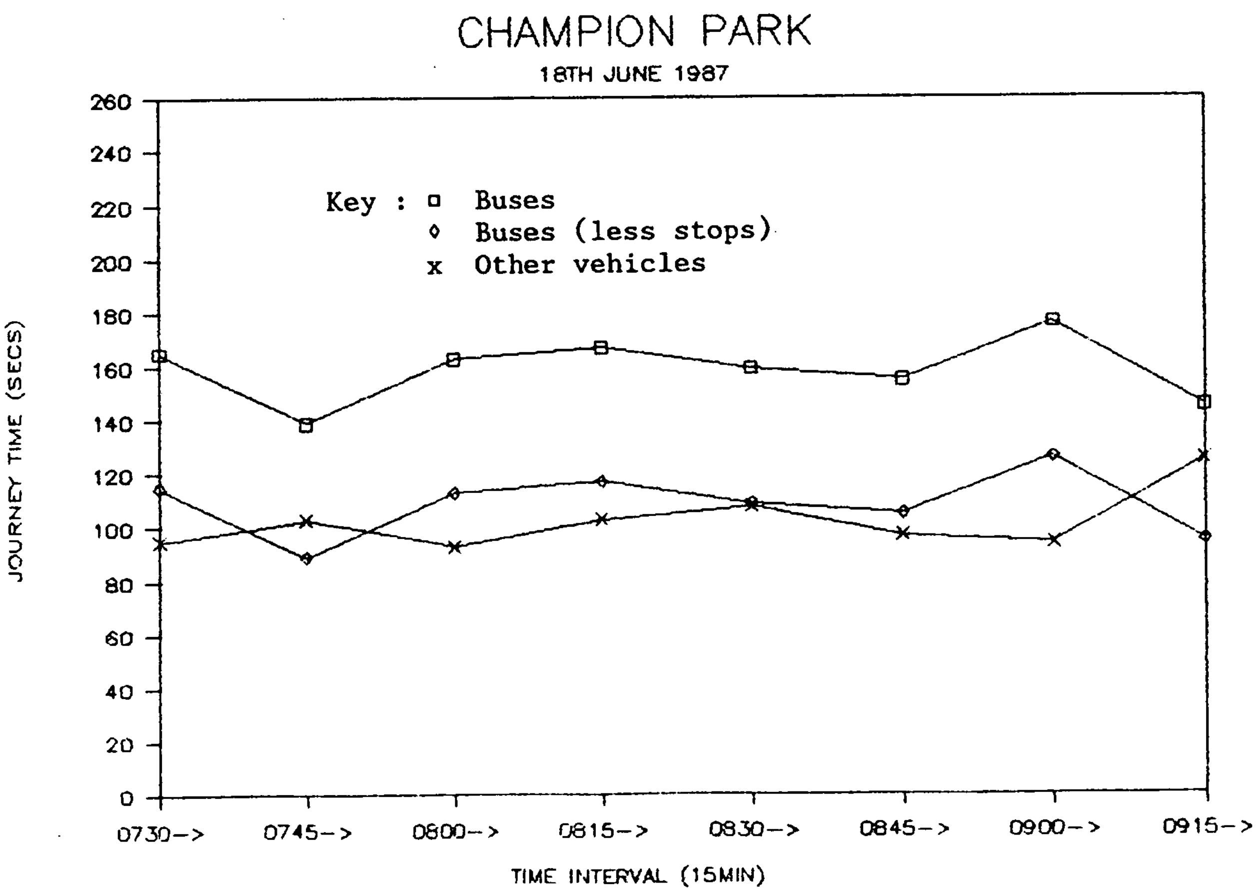


FIGURE F13 : AVERAGE JOURNEY TIMES

AFTER SURVEYS





INPUT DATA FOR CONTRAM FOR "WITHOUT" BUS LANE MODELLING

NETWORK AND TIME DATA   LONDON BEFORE BUS LANE   2-DAY AVERAGE

CARD TYPE	TIME UNIT (SECS)	TIME INTERVAL BOUNDARIES FOR SIMULATION PERIOD. (HOURS AND MINUTES) INTERVAL NUMBER : 1	2	3	4	5	6	7	8	9	10	11	12	13
1	1	715	730	745	800	815	830	845	900	915	930	1030	0	0

CARD TYPE	ORIGIN NUMBER	FEEDS UP TO 5 LINKS : (LETTERS DENOTE BANNED MOVEMENTS)				
3	5001	101	0	0	0	0
3	5002	202	0	0	0	0
3	5003	302	0	0	0	0
3	5004	701	0	0	0	0
3	5005	702	0	0	0	0

CARD TYPE	FREE LINK NUMBER	FEEDS UP TO 5 LINKS OR DESTINATIONS : (LETTERS DENOTE BANNED MOVEMENTS)					CRUISE TIME (SECS)	LENGTH (METRS)	SAT,N FLOW (PCU/H)	STORE CAP. (PCUS)	JUNCTION NUMBER
4	201	402	0	0	0	0	15	223	1800	41	20
4	202	402	102	0	0	0	33	500	1800	91	20
4	301	401	0	0	0	0	13	195	3600	71	30
4	401	501	0	0	0	0	28	422	3600	153	40
4	501	9002	601	0	0	0	10	154	3600	56	50
4	801	9003	602	0	0	0	48	715	1800	210	80

CARD TYPE	GIVE-WAY LINK NUMBER	FEEDS UP TO 5 LINKS OR DESTINATIONS : (LETTERS DENOTE BANNED MOVEMENTS)					CRUISE TIME (SECS)	LENGTH (METRS)	SAT,N FLOW (PCU/H)	STORE CAP. (PCUS)	GIVES WAY TO LINK NUMBERS A	B	-CAP,Y SLOPE *100	JUNCTION NUMBER
5	302	401	0	0	0	0	33	500	1500	91	301	0	22	30
5	402	501	0	0	0	0	43	643	600	117	401	0	22	40
5	502	9002	601	0	0	0	51	610	600	111	501	0	22	50

CARD TYPE	SIGNL,D LINK NUMBER	FEEDS UP TO 5 LINKS OR DESTINATIONS : (LETTERS DENOTE BANNED MOVEMENTS)					CRUISE TIME (SECS)	LENGTH (METRS)	SAT,N FLOW (PCU/H)	STORE CAP. (PCUS)	SIGNAL /JUNCT NUMBER	STAGE WHEN GREEN	STAGE GREEN %	LINK DELAY %
6	101	201	301	0	0	0	33	500	3600	182	10	1	100	100
6	102	301	0	0	0	0	15	223	1800	41	10	2	100	100
6	601	9001	0	0	0	0	10	154	2249	56	60	1	100	100
6	602	9001	0	0	0	0	8	99	2421	25	60	2	100	100
6	701	801	502	0	0	0	33	500	3600	182	70	1	100	100
6	702	801	502	0	0	0	33	500	1800	91	70	2	100	100

CARD TYPE	SIGNAL NUMBER	LOST TIME (SECS)
7	10	10
7	60	10
7	70	10

The 'boxed' values are changed for the 'with' bus lane modelling as follows:
3600 to 1800. 153 to 123. 56(link 501) to 28
2249 to 2207. 2421 to 2387. 56(link 601) to 36.

CARD TYPE	PCUS PER CLASS CAR	B	L	CRUISE TIMES(% CAR VALUE) CAR	B	L
9	1.0	1.0	0.0	100	100	0

CARD TYPE NO.	VEH CLASS	FUEL COEFFICIENTS DISTANCE A	B	C	DELAY A	B	C
10	C	164	240	200	150	107	340
10	B	492	720	600	450	321	1020

6 UNCONTROLLED LINKS
3 GIVE-WAY LINKS
6 SIGNALIZED LINKS
15 LINKS IN ALL

DESTINATIONS DEDUCED FROM LINK DATA:-
9002 9003 9001

TRAFFIC DEMANDS

BEFORE SURVEY 2-DAY AVERAGE

ORIG NO.	DEST NO.	PKT SIZE (VEH)	LIN. DIST (MTR)	ENTRY FLOW-RATE IN TIME INTERVALS (VEH/HR) : 1	2	3	4	5	6	7	8	9	10	11	12	13
5001	9001	2C		511	511	465	506	533	620	560	544	549	0			
5001	9002	1C		134	134	121	133	140	160	146	140	144	0			
5002	9001	1C		24	24	22	26	26	29	27	26	27	0			
5003	9001	2C		434	434	391	432	454	540	483	470	479	0			
5004	9001	2C		778	778	788	808	888	876	780	642	580	0			
5004	9003	2C		304	304	306	318	344	340	304	250	226	0			
5005	9001	1C		81	81	74	80	85	99	90	86	87	0			

TOTAL VEHICLE FLOW RATES FROM EACH ORIGIN (VEH/HR)

ORIGINS	FLOWS									
5001	645	645	586	639	673	780	706	684	693	0
5002	24	24	22	26	26	29	27	26	27	0
5003	434	434	391	432	454	540	483	470	479	0
5004	1082	1082	1094	1126	1232	1216	1084	892	806	0
5005	81	81	74	80	85	99	90	86	87	0

TOTAL VEHICLE FLOW RATES DIRECTED TOWARDS EACH DESTINATION (VEH/HR)

DESTINATIONS	FLOWS									
9002	134	134	121	133	140	160	146	140	144	0
9003	304	304	306	318	344	340	304	250	226	0
9001	1828	1828	1740	1852	1986	2164	1940	1768	1722	0

TOTAL VEHICLE FLOW RATES ENTERING THE NETWORK (VEH/HR)

2266	2266	2167	2303	2470	2664	2390	2158	2092	0

APPENDIX G

GLOSSARY OF TERMS

APPENDIX G

GLOSSARY OF TERMS

This glossary contains explanations (not necessarily strict definitions) of a number of terms used in the main report.

Assignment	The route followed by a vehicle through the transportation system
Bus Bay	A facility, usually at bus stops, where buses can stop without impeding the general traffic flow
Capacity	The maximum traffic flow that can pass a specified point (e.g. the stop-line of an approach to a signal controlled junction) under prevailing operating conditions (e.g. signal timings)
Contra-Flow Bus Lane	A lane reserved in a one-way street for buses (and other specified priority vehicles) travelling in the opposite direction to the general traffic
Circulating Traffic	Traffic negotiating the internal (circulating) sections of a roundabout which have priority over entering traffic
Constriction	A reduction in road/carriageway width (e.g. due to a bridge crossing)
Cruise Speed	The average speed of vehicles along a link under right-of-way conditions (e.g. where no queueing or stopping at traffic signals is involved)
Cycle	One complete sequence of signaling operations. The cycle time is the time taken for completion of this sequence

Degree of Saturation	The ratio of the flow to the maximum flow which can be passed through the intersection from the particular approach under prevailing operating conditions (e.g. signal timings)
Delay	The difference between the average journey time through the intersection and the 'cruise' time (i.e. the time taken under right-of-way conditions)
Destination	The terminating point of a journey (or, in the network modelling, the point at which vehicles leave the network)
Effective Green Time	The sum of the green period and the amber period less the lost time for the particular phase
Exit Blocking	The situation where an exit from a junction becomes blocked (usually by congestion)
Exit Constriction	A narrowing of an exit from a junction (e.g. due to physical constraints, parking, etc.) which causes a reduction in entry capacity
Flare	The widening of the approach to a junction so that the road width at the junction entry is greater than that on the approach
'Floating Car' Technique	A technique for measuring the average journey time of a traffic stream using observers within vehicles which are driven at the same speed as the general traffic
Flow	The average number of vehicles passing a given point on the road in the same direction per unit time

Headway	Distance headway: The distance between similar points on consecutive vehicles (e.g. the rear) Time headway: The time difference between consecutive vehicles passing a single point (usually between the rear of vehicles when measurements taken at junction stop-lines)
Intergreen Time	The time from the end of the green period of the phase losing right-of-way to the beginning of the green period of the phase gaining right-of-way
Lost Time	The time in each phase of a cycle which is effectively lost to traffic movement because of starting delays and the falling-off of the discharge rate during the amber period (e.g. acceleration and deceleration effects)
Modal Split	The division of journeys into their different methods (or modes) of travel (e.g. public transport, private car, etc.)
Offset	The difference in the start of green time between adjacent junctions
Origin	The starting point of a journey (or, in the network modelling, the point at which vehicles enter the network)
Packing Factor	The ratio of the average number of vehicles using the setback to the maximum number who could use it, under heavy traffic conditions (i.e. when queues extend upstream of the start of the setback)

Passenger Car Unit (PCU)	A factor used to represent the effect of different traffic compositions (i.e. types of vehicle) on traffic flow (e.g. a bus is approximately equivalent to 2 passenger cars[17])
Phase	The sequence of conditions applied to one or more streams of traffic which, during the cycle, receive simultaneous identical signal indications
Saturation Flow	The average rate of flow (usually across the stop-line) over that portion of the green period during which there is a queue (excluding periods when acceleration and deceleration effects occur - usually taken as the first and last 6 seconds of the green period)
Setback	The space in the nearside lane between the end of a bus lane and the stop-line (or give-way line) which can be used by general traffic
Taper	The deflection marked on the carriageway at the start of a bus lane which facilitates the merging manoeuvre for non-priority traffic
Traffic Demand	The average number of vehicles arriving on a particular link/route in the same direction per unit time
Traffic Intensity	The ratio of traffic demand (i.e. arrival flow) to junction capacity. This is equivalent to the degree of saturation at signal controlled junctions
With-Flow Bus Lane	A lane reserved for buses (and other priority vehicles) travelling in the same direction as the general traffic